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# ANALYSIS OF A STANDARD SAMPLE OF THE CARBURETTED WATER-GAS TYPE BY LABORATORIES CO-OPERATING WITH THE AMERICAN SOCIETY FOR TESTING MATERIALS

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## ABSTRACT

This is a report of the analysis of a standard sample of carburetted water-gas by 24 laboratories in cooperation with Subcommittee VII of Committee D-3 of the American Society for Testing Materials. The data are presented in a series of frequency distribution plots, which show at a glance how the analyses compare with respect to each component of the gas mixture, as well as the calculated heating value and specific gravity. These plots form a clear picture of this type of gas analysis in this country. Although some very creditable work was reported, the need for some standardization is evident.

## CONTENTS

	Page
I. Task of Committee ASTM D-3-VII on the analysis of gaseous fuels.....	314
II. Cooperating laboratories.....	314
III. Preparation of standard gas sample ASTM D-3-VII-1.....	315
IV. Other instructions and information furnished with the standard sample.....	317
V. Volumetric reproducibility of the analytical apparatus used by the cooperating laboratories.....	318
VI. Apparatus and methods used for the analysis of standard gas sample ASTM D-3-VII-1.....	321
1. Apparatus.....	321
2. Methods of analysis.....	322
VII. Results of the cooperative analysis of the standard gas sample ASTM D-3-VII-1.....	323
1. Manner of presenting the analytical data.....	323
2. Specific gravity calculated from the analyses compared with the known specific gravity.....	324
3. Calculated heating value compared with measured heating value.....	327
4. Comparison of laboratories.....	330
5. Carbon dioxide.....	330
6. Oxygen.....	331
7. Ethylene.....	332
8. Carbon monoxide.....	333
9. Hydrogen.....	334
10. Methane and ethane.....	336
11. Nitrogen.....	336
12. All constituents.....	336
VIII. Conclusions.....	337
IX. Addenda. A comparison of results obtained by the mass spectrometer with analyses by the conventional volumetric methods of absorption and combustion.....	338
	313

## I. TASK OF COMMITTEE ASTM D-3-VII ON THE ANALYSIS OF GASEOUS FUELS

Subcommittee VII of Committee D-3 of the American Society for Testing Materials has been assigned the task of standardizing the analysis of gaseous fuels. The Subcommittee is approaching this task with certain reservations derived from an acquaintance with gas-analysis methods, gas-analysis apparatus, and gas analysts. The reason for such reservations usually become apparent when a gas analyst is asked to substitute a new reagent, pipette, procedure, method—or a whole new apparatus or system of analysis—for one that he has been using satisfactorily. Such a request is unamiable and might very often be unreasonable. Indeed, if it can be demonstrated by actual measurement that an apparatus or method now in use will give satisfactory results, there is no real justification for insisting that it be discarded in favor of another which may be sponsored as the official instrument of some group.

Since it seems reasonable and fair to approve as standard any apparatus and method capable of giving satisfactory analytical results, it remains only to decide what are satisfactory analytical results, and which methods and apparatus will yield these results. To reach these decisions, two steps are being taken.

First, the various purposes to be served by the analytical data are listed, and the necessary accuracy with which each component of each type of fuel gas must be known in order to serve each specific purpose is then estimated. These estimates afford the first criterion by means of which the suitability of analytical methods and apparatus may be judged, but they are subject to revision when more is known about the limiting attainable accuracies of the analytical methods, and also when the significance of the term "necessary" in the phrase "necessary accuracy" has been evaluated with more realism than enthusiasm.

Second, the accuracy and reproducibility of existing apparatus and methods are being measured by the direct procedure of a series of cooperative analyses of standard gas samples of various types. (Although these samples are being prepared at the National Bureau of Standards, they are not to be confused with the Bureau's series of Standard Samples available for purchase. These gas samples are being prepared for free distribution to laboratories cooperating with ASTM Committee D-3 in this project.)

The analytical results obtained so far from the examination of these standard samples represent our first clear picture of gas analysis in this country.

This paper reports the results of the analysis of the first standard sample of a planned series. The sample is of the carburetted water-gas type for analysis by the conventional volumetric absorption and combustion methods.

## II. COOPERATING LABORATORIES

Cooperating laboratories include those of State and Federal agencies and of colleges, but the greatest contribution has come from the laboratories of the gas, petroleum, and steel industries. The laboratories are located throughout the United States. They are equipped with many types of apparatus, mostly modern, and employ different analytical methods. These methods and apparatus will be noted



with the presentation of the analytical data. Taken as a whole, the work represents the best present-day American practice.

Of the 24 laboratories that analyzed the carburetted water-gas sample, all but one (a college) employed chemists specifically trained in gas analysis. One laboratory used high-school talent, 1 used high-school and college graduates, 17 used college graduates, and 5 answered "yes" to the question, "Do these men (gas analysts) have the equivalent of high-school or college education?" Nineteen of the laboratories did gas analysis regularly and 5 (mostly colleges) intermittently.

Most of the cooperating laboratories preferred anonymity, and the names of all are accordingly withheld from publication. This has the advantage of placing the results on an impersonal basis, which removes any inhibition to the open expression of constructive criticism and provides no stimulus for an unamiable discussion of results. It does deprive one of the chance to appraise the likely worth of results from a laboratory whose equipment, personnel, and operation are well known from personal observation. Appraisal based on this sort of acquaintance is of real value in a good practical sense, but is not an actual requisite in a cooperative study of this sort. Anonymity is also a pseudonym for modesty in this instance, for it has deprived many of the laboratories of taking credit for really fine work.

### III. PREPARATION OF STANDARD GAS SAMPLE ASTM D-3-VII-1

Standard Sample ASTM D-3-VII-1, carburetted water-gas type, was prepared to conform with the range of composition at present accepted by Subcommittee VII, which is

	Percentage by volume
CO <sub>2</sub> -----	6 to 1
O <sub>2</sub> -----	1 to 0.2
N <sub>2</sub> -----	10 to 2
"Illuminants"-----	15 to 5
H <sub>2</sub> -----	45 to 30
CO-----	40 to 30
CH <sub>4</sub> -----	17 to 5
C <sub>2</sub> H <sub>6</sub> +-----	3 to 2

The sample was made up from the following compressed gases obtained from commercial sources:

Type of gas	Approximate purity	Chief impurity
	<i>Percent</i>	
CO <sub>2</sub> -----	99.9	Air
O <sub>2</sub> -----	99.7	N <sub>2</sub>
N <sub>2</sub> -----	99.5	O <sub>2</sub>
C <sub>2</sub> H <sub>4</sub> -----	99.5	Homologues
H <sub>2</sub> -----	99.7	O <sub>2</sub>
CO-----	99.7	H <sub>2</sub>
CH <sub>4</sub> -----	99	N <sub>2</sub> and C <sub>2</sub> H <sub>6</sub> +
C <sub>2</sub> H <sub>6</sub> -----	98	C <sub>2</sub> H <sub>4</sub> and C <sub>3</sub> H <sub>8</sub>

As this sample was not prepared from gases of known high purity, its actual composition was not known. Its heating value and specific gravity were carefully measured. The sample, therefore, serves three definite purposes, as it will establish (1) reproducibility,<sup>1</sup> (2) ability to compute correct heating value, and (3) ability to compute correct specific gravity. It will not serve as a final criterion of *accuracy*,<sup>1</sup> except in respect to the computation of heating value and specific gravity, as the composition was not predetermined.

The sample was prepared under a pressure of 350 psi in the large storage and mixing tank used to prepare the mixtures for the Bureau's study of specific-gravity instruments.<sup>2</sup> After very thorough mechanical mixing, the uniformity of the sample was definitely established by sampling from various parts of the tank and measuring any difference in composition by means of a 1-m Zeiss gas interferometer. The sample was then transferred to small sample cylinders as follows:

1. The sample cylinders, equipped with needle valves having vacuum-tight packing, were connected to a single welded manifold by means of high-pressure unions. The large mixing tank and a vacuum pump were connected to this same manifold. The whole system, including the manifold and opened sampling cylinders, was evacuated to 0.0001 mm Hg pressure overnight. Thereafter, with vacuum pump disconnected, the increase of pressure within the whole system was less than 0.0001 mm during the first hour. Much less than 1 hour was required to transfer the gas sample from the mixing tank to the sample cylinders. Contamination from leakage was, therefore, quite insignificant.

2. The small cylinders were flushed with the sample from the mixing tank by alternate filling to 2 atm and evacuating to 1 mm Hg. After the third flushing, the sample cylinders were filled to 320 psi. With full pressure on the manifold, the sample cylinders were then closed. The manifold was then opened to a water seal, and no leakage from the cylinders was observed overnight.

3. All the sample cylinders issued for the cooperative analysis of this sample were thus filled simultaneously from the manifold connected to the single, uniform source of supply. The samples were, therefore, identical at the date of issue.

The sample was issued in February 1940. During March, April, May, and June, 18 of the 24 cooperating laboratories reported, and of the remaining 6 laboratories, 4 reported in July, 1 in August, and 1 in September. As the sample contained carbon monoxide under pressure in steel, the question of a significant change in composition because of the formation of iron carbonyl has been raised. Although this reaction no doubt occurred to some slight extent, it apparently did not alter the composition of the sample by any significant amount. During the first 4 months, when most of the analyses were performed, the measurements of specific gravity indicated a lowering of 0.0002. This corresponds to approximately 0.04 percent by volume of carbon monoxide. In 4 years' time, the measured heating value of the gas, still stored under pressure in steel, was 0.8 Btu lower than indicated

<sup>1</sup> Lest there be any confusion as to the meaning of the terms "accuracy" and "reproducibility," it should be stated that the conventional concepts are here implied. Accuracy is measured in terms of agreement with a true value; reproducibility is measured in terms of the mutual agreement of a series of measurements of the same property of a substance. As a matter of convenience, reproducibility has long served the gas analyst in lieu of a definite measurement of accuracy. Eventually this situation will be corrected.

<sup>2</sup> F. A. Smith, J. H. Eiseman, and E. C. Creitz, Tests of instruments for the determination, indication, or recording of the specific gravities of gases, Misc. Pub. NBS M177. [Publication pending.]

by the original measurement. This is in the wrong direction to be accounted for by loss of carbon monoxide. A loss of 1 percent of carbon monoxide would have raised the heating value of this sample 3 Btu. Finally, the analyses from March to September show no significant trend, down or up, with respect to the carbon monoxide found.

It is accordingly entirely reasonable to assume that identical samples were analyzed in all the laboratories, provided the samples were introduced into the apparatus for analysis without contamination.

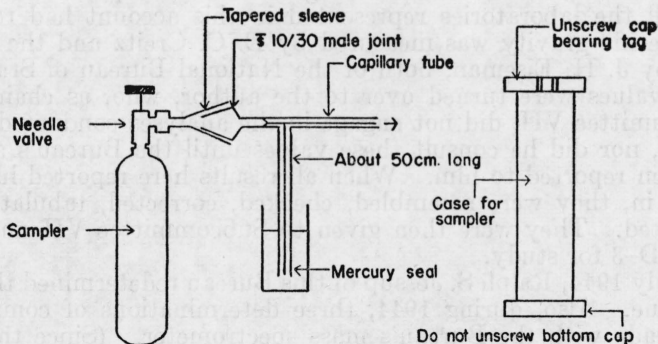
To avoid contamination while transferring the sample to the burette the following illustrated instructions for a definite procedure were furnished the laboratories.

#### INSTRUCTIONS REGARDING SAMPLER AND SAMPLING

1. The cylinder containing the sample is shipped in a metal case made from standard pipe fittings. Save this for return of the cylinder, which must be returned immediately upon completion of your analyses.

2. The cylinder is equipped with a very special vacuum-type needle valve. do not close this valve with anything but the thumb and one finger. do not force the valve shut. If too much twist is applied to the valve handle, the seat will be ruined.

3. Remove the dust cap from the valve and attach the sampling fitting, which terminates in a thin brass tapered sleeve. This sleeve fits a standard glass interchangeable joint, male part, size  $\frac{1}{8}$  10/30. This glass joint should be sealed to the brass sleeve by a thermoplastic cement of the DeKhotinsky type, or other cement capable of making a gas-tight joint. We find the arrangement sketched below desirable.



With cock of burette closed, gently open needle valve until gas bubbles out through mercury seal. When this line is flushed, take gas into burette and discard until horizontal portion of sampling line is flushed. About 50 ml in all is adequate for flushing capillary lines. Leave connected to burette for next sample to be taken. Use mercury seal as manometer to avoid sampling under reduced pressure. If direct glass seal or interchangeable joint is not used in connecting to burette, flush sampling line each time with about 20 ml of gas. For convenience and safety, we prefer interchangeable joints secured with DeKhotinsky or a heavy lubricant.

#### IV. OTHER INSTRUCTIONS AND INFORMATION FURNISHED WITH THE STANDARD SAMPLE

In addition to the sampling instructions, these general instructions were issued,

## INSTRUCTIONS REGARDING ANALYSIS AND RECORDING OF DATA

(1) The sampler should yield about 6 liters of gas, an amount adequate for flushing, saturating the reagents, and a good many analyses. Make at least 10 analyses. If possible, several analysts should each perform a group of 10 determinations.

(2) Report the data completely, including all burette readings, formulae used in computation, and relevant notes. Tabulate these data on a single sheet of paper.

(3) Furnish a photograph of the apparatus used at the time these analyses are performed. The committee desires this.

(4) For the sake of uniformity, compute the heating values from table 14 given on page 38 of NBS Circular C417, Calorimeter Tables, considering "Illuminants" as ethylene. If you wish to take exception to these values, state this and compute a second heating value as you wish.

(5) For the sake of uniformity, compute densities from the table given on page 3, volume 3, International Critical Tables.

(6) If you have not already given a description of the analytical apparatus used, include this. If a standard model, give name and cite reference. Note any modifications of your own.

In addition to these instructions, the following information was furnished with each sample.

(1) The *range* of composition as previously noted, with a list of the gases used to prepare the sample, also previously given.

(2) The range of heating value was expressed as 500 to 600 Btu per ft.<sup>3</sup>

(3) A brief description of the preparation of the sample to show the cooperating laboratories that each one received the same sample.

In no case did any analyst who made any of these determinations have any other knowledge of the properties of this sample, nor was any information other than that given above imparted to anyone until all the laboratories represented in this account had reported. The specific gravity was measured by E. C. Creitz and the heating value by J. H. Eiseman, both of the National Bureau of Standards. These values were turned over to the author, who, as chairman of Subcommittee VII, did not engage in the analyses conducted at this Bureau, nor did he consult these values until the Bureau's analyses had been reported to him. When all results here reported had been turned in, they were assembled, checked, corrected, tabulated, and illustrated. They were then given to Subcommittee VII and Committee D-3 for study.

In July 1944, Ralph S. Jessup of this Bureau redetermined the heating value. Also, during 1944, three determinations of composition were made with the Bureau's mass spectrometer. (Since the cooperative analyses had been reported, the 1944 measurements could have been made with a knowledge of the results previously obtained. Actually, no reference was made to previous results, with the single exception of the final analyses by the mass spectrometer.)

## V. VOLUMETRIC REPRODUCIBILITY OF THE ANALYTICAL APPARATUS USED BY THE COOPERATING LABORATORIES

As we are dealing here with a volumetric analysis, the accuracy is fundamentally limited by the measurement of the gas volumes involved during the course of an analysis—and this is so obvious that it is often forgotten. Just to make sure that everything was in order before the standard sample was analyzed, and also to evaluate the



volumetric system (including its operator), each laboratory was asked to perform a series of simple measurements. The instructions are here reproduced.

#### VOLUMETRIC REPRODUCIBILITY OF APPARATUS

In addition to obtaining the analytical data, make the following measurements, using air as the gas to be measured. These measurements can well precede the analyses.

(1) Take approximately 90 ml of air into the burette, balance the pressure, and read the volume. Destroy balance, rebalance, and read again. Make and record 10 such measurements. Note temperature of water jacket.

(2) Now raise the temperature of the water in water jacket 2 degrees centigrade, and repeat measurements as made above.

(3) and (4) Repeat (1) and (2) with approximately 30 ml of air in the burette.

(5) Take three successive portions of about 30 ml of air, measure each and transfer to combustion pipette, then return and measure combined volume of the three portions. Repeat this procedure three times. Record all data.

(6) Measure approximately 50 ml of air in burette. Now place burette and distributor and manometer under a reduced pressure, which will not quite upset manometer, allow to stand thus 10 minutes, rebalance and read volume.

(7) Repeat (6), but place under positive pressure. If (6) or (7) shows presence of leaks, locate and repair before proceeding with analyses.

These simple measurements proved to be of no significance to some laboratories, but were of real interest to others. Several faulty burettes, supposedly calibrated, were discovered and actually calibrated. Some analysts who had presumed that 30 ml + 30 ml + 30 ml, measured separately, would always equal a measured 90 ml found that this was not always exactly so. Some analysts conducted an inert gas on a tour throughout the apparatus, wandering over the various reagents, through the copper oxide, into the slow combustion pipette, and always back to the burette to see if there was loss or gain, or a comforting absence of either. Such diversions are always profitable.

It was noticeable that some analysts read volumes to the nearest 0.1 ml, others to the nearest 0.05 ml, and still others to the nearest 0.01 or 0.02 ml. Those who read to 0.1 ml sometimes lift an eyebrow at those who read to 0.01 or 0.02 ml. Now, insofar as the actual estimation of volume is concerned, the modern burette, with all lines engraved over halfway around the circumference and spaced longitudinally at least 1 mm and not over 2 mm apart, can be read rather easily with a reproducibility corresponding to 0.02 ml. The usual burette is marked in intervals of 0.2 ml, and the lines bounding this interval are about 1.2 to 1.5 mm apart. There are numerous instances in many laboratories where tenths of a millimeter are independently estimated by different observers with excellent agreement. This case is no exception, and this has been demonstrated by many years of independent observation with various observers checking one another. It has also been demonstrated by moving a chromium-plated rod, shaped to correspond to a mercury meniscus, within a tube, graduated to correspond to a gas analysis burette, and checking the estimated portion of the rod with its actual position measured by means of a micrometer head. It is true that errors induced by faulty temperature-pressure compensation and saturation may be greater than the

0.02 ml estimated in reading the burette, but this is no real argument against getting what is readily available from the burette.

The fact that three standards of reading were employed makes a comparison of the prescribed volumetric measurements rather difficult, as it is possible that where no deviation was noted on any test, an actual deviation was within the limit of 0.1 ml, and conversely where deviations of 0.1 ml are reported, they may actually have been somewhat less. The data have been condensed and are tabulated in table 1. The first column gives the laboratory number. The next four columns give the average change in volume noted in tests 1 to 4, inclusive, previously noted. The succeeding columns give the differences in volumes noted during test 5, and the average of these differences. This last average is the arbitrary volumetric reproducibility noted in the tables of analytical results to follow.

TABLE 1.—*Measurement of volumetric reproducibility and accuracy of all apparatus used*

Lab. No.	Test number										Average of test 5
	1	2	3	4	5						
	ml	ml	ml	ml	ml	ml	ml	ml	ml	ml	ml
1	0	0	0	0	0.2	0.1	0.2				0.17
2	0	0	0	0	0.06	0.03	0.04	0.03	0.03		0.04
3	0	0.54±.17	(*)	(*)	.1	.1	.1	.4	.1	0.2	.17
4	0	0	0	0	.9	.6	.5				.7
5	.01	0.01	.01 to .02	.01	.03	.02	.06				.04
6	0	0	0	0	0	0	.05				.02
7	.01	0	0	0	.05	.05	.05				.05
8	.02	0.02	0.04	.02	.1	.2	0				.1
9	.04	0.03	0	.01	.2	.2	.3				.23
10	.02	0.02	0	.03	.2	.2	.1				.17
11	.01	0.02	0.01	.01	.02	0	0				.01
12	.05	0.05	0.05	.05	.1	0	0.05				.05
13	0	0	0	0	0	0	0				0
14	.02	0.02	0.02	.02	(b)	(b)					
15	0	0	0	0	0	0	0				0
16			(*)	(*)							
17	0	0.01	0	0	.05	.05	0				.03
18	.02	0	0	.03	0	0	0				0
19	.02	0.02	0.02	.01	.1	.1	.1				.1
20			(*)	(*)							
21	.01	0	0	0	0	.01	.08				.03
22	0	0	0	0	.2	.1	0				.1
23	.01	0	0	0	.4	.25	.2				.3
24	.02	0.02	0.02	.02	.02	.02	.02				.02

\* Not done.

b Incomplete.

Tests 1 and 3 were simple measures of volumetric reproducibility as it might be affected by the manometric system and the ability of the analyst to adjust pressures and read volumes. This test also measures the ability of the apparatus to maintain the meniscus of the confining liquid within the burette in the fixed position corresponding to the proper pressure balance until the volume is determined. This becomes important when there is no stopcock to arrest the flow of confining fluid between burette and leveling bulb, especially when the analyst must hold the leveling bulb while reading the volume—no task for a nervous man. A glance at the tabulated data shows no differences greater than 0.05 ml and average reproducibility of about 0.02 ml.

Tests 2 and 4 measured the volumetric reproducibility as it might be affected by a change of temperature and a corresponding change in equilibrium in the pressure-temperature compensation. The conventional pressure-temperature compensator was part of the regular equipment of most of the apparatus used. This device is certainly one of the most convenient bestowed upon gas analysts, and the greatness of its convenience has dulled curiosity concerning its behavior. It is essentially a differential gas- and vapor-pressure thermometer, and it can be reasonably expected to react accordingly with respect to changing temperature. If the degree of this reaction is the same in burette and compensating tube, all is well. But uniformity of temperature within the water jacket and rate of heat transfer into the burette and compensator may not always be favorable, particularly as regards saturation with respect to water vapor in the compensator with a rising temperature. It is accordingly comforting to note no change in apparent volume greater than 0.05 ml, with an average of about 0.02 ml, reported from tests 2 and 4. There is one exception. Laboratory 3 reported fairly large changes of volume with rising temperature. The apparatus involved was not equipped with a pressure-temperature compensator, so that such an effect was to be expected. However, the average change was  $0.54 \pm 0.17$  ml per degree centigrade for an average volume of 76.4 ml; the expected change in the temperature range existing was 0.40 ml per degree centigrade; the reproductibility ( $\pm 0.17$ ) is not too comforting.

Test 5 is a measurement of volumetric accuracy, and illustrates that the total volume may not equal the sum of its parts as actually measured. The data rather speak for themselves, although the fact that some series of readings were made to the nearest 0.1 and others to the nearest 0.01 precludes any close comparisons. This simple test was the means of discovering several burettes that were in error by really significant amounts, although they were presumably calibrated instruments.

In no case were leaks discovered and reported during tests 6 and 7. We can then assume that the apparatus used, insofar as the measurement of volumes is concerned, was free from leakage.

## VI. APPARATUS AND METHODS USED FOR THE ANALYSIS OF STANDARD GAS SAMPLE ASTM D-3-VII-1

### 1. APPARATUS

It has been stated that most of the analytical apparatus used in this cooperative investigation was of the modern type. The apparatus may be classified with respect to the system of volume measurement, the arrangement of pipettes or reaction tubes, and the confining fluid. For convenience, a set of abbreviations is used.

$V_1$ —Volumes are made comparable by means of a pressure-temperature compensator with manometer interposed between the compensating tube and the burette.

$V_2$ —Pressure within the burette is balanced against existing barometric pressure, and gas volumes are corrected from the observed pressure and temperature to a common basis, including a correction for changes in the saturation pressure of water.

$V_3$ —Pressure in burette is balanced against atmospheric pressure, but no correction is made for changes in pressure or temperature during analysis.

$V_4$ —Volumes are measured by observing the pressure exerted within a constant volume.

$R_1$ —Pipettes are connected to the burette by a manifold.

$R_2$ —A single pipette, connected to the burette, serves for all reactions.

$R_3$ —Pipettes are temporarily connected in succession to the burette as the different reactions are progressively conducted.

$R_4$ —The burette itself serves as a reaction tube.

Hg—Mercury is used as the confining fluid.

$H_2O$  (with appropriate subscript)—An aqueous solution serves as the confining fluid.

Thus the abbreviation  $V_1R_1Hg$  designates an apparatus equipped with pressure-temperature compensator and manometer, manifold connecting pipettes to burette, with mercury serving as the confining fluid. Twenty of the twenty-four laboratories used this type of apparatus. One laboratory used this type with acidified water as the confining fluid. One used a Bone and Wheeler apparatus, which is widely employed in Great Britain. This would be abbreviated  $V_4R_2Hg$ , as it is equipped with a constant volume burette and one permanently connected pipette. It is not as convenient to use as the models more favored in America, but does greatly reduce the errors caused by physical-solubility of gases in the various reagents. One laboratory used an apparatus without compensator, but with manifold to connect pipettes ( $V_2R_1Hg$ ). And finally, one laboratory used a Hempel apparatus ( $V_2R_3Hg$ ).

Photographs of all the apparatus actually used were requested, and 18 were submitted. These are not reproduced in this paper, but are on file if needed. In general, they show that modern apparatus in good condition was used.

## 2. METHODS OF ANALYSIS

When all the reports were assembled, it was evident that three major methods of analysis had been used. For abbreviation and identification in the figures, they are designated by roman numerals and are outlined below.

### *Method I:*

Carbon dioxide was determined by absorption in a solution of potassium or sodium hydroxide.

Ethylene ("Illuminants") was determined by absorption in fuming sulfuric acid or bromine.

Oxygen was determined by absorption in a solution of potassium pyrogallol or in a chromous solution.

Carbon monoxide was determined by absorption in solutions of cuprous chloride (in various modifications).

Hydrogen was determined by combustion over hot copper oxide.



Hydrocarbons (remaining) were determined by combustion over hot platinum in the presence of excess oxygen, and computed as  $\text{CH}_4$  and  $\text{C}_2\text{H}_6$  from the measurement of contraction after burning and carbon dioxide produced by the combustion. Nitrogen was computed by difference from 100.

*Method II:*

This method differs from I in the following respect:

Carbon monoxide and hydrogen were determined by burning together over hot copper oxide, with subsequent absorption of carbon dioxide produced.

*Method III:*

This method differs from I in the following respects:

Carbon monoxide, hydrogen, and hydrocarbons were burned in a single combustion over hot platinum in the presence of excess oxygen and computed as  $\text{CO}$ ,  $\text{H}_2$ , and  $\text{CH}_4$  from the observed contraction after combustion, carbon dioxide produced, and oxygen consumed.

Nitrogen was determined by measurement of the unreacted residue at the end of the analysis, corrected for known amounts of  $\text{N}_2$  added during the analysis.

Of secondary importance, and applying to the tabulated data rather than the frequency plots, are arabic figures, which follow the roman numerals designating the major methods. The first figure indicates whether oxygen was absorbed by potassium pyrogallol (1) or in a chromous solution (2). The second figure indicates whether ethylene was absorbed in fuming sulfuric acid (1) or bromine (2).

Thus the abbreviation I-1-1 indicates that the carbon monoxide was determined by absorption, and that oxygen was absorbed in "pyro" and ethylene in fuming sulfuric acid. The abbreviation II-2-2 indicates that the carbon monoxide and hydrogen were determined with copper oxide, and that the oxygen was absorbed in a chromous solution and the ethylene in bromine.

## VII. RESULTS OF THE COOPERATIVE ANALYSIS OF THE STANDARD GAS SAMPLE ASTM D-3-VII-1

### 1. MANNER OF PRESENTING THE ANALYTICAL DATA

All the analytical data submitted have been tabulated, and these tabulated data have been condensed by computing average values, which in turn have been tabulated. But contemplation of these tabulated data for some hours would not serve to reveal what may be seen at a glance when the same data are presented in a series of frequency-distribution plots. Accordingly, these plots, which amount to actual pictures of the analytical data, are presented first, with occasional reference to table 2, which gives the average values from each laboratory. Thereafter, table 3, which contains all of the analytical data reported, can be studied by those interested in any details that have not been shown by the plots. These two tables are given at the end of the paper.

Each circle appearing on the frequency-distribution plots represents a value derived from a single analysis (except for plots representing averages from each laboratory). The circles are plotted equidistant on the ordinate corresponding to their value. Thus the abscissas are values derived from the analyses, and the ordinates indicate the frequency with which these values occur. For example, in the top section of figure 1, nine circles on the ordinate corresponding to the value 0.650 indicate the fact that nine separate analyses yielded a value of 0.650 for the specific gravity of the sample. Similarly, 11 analyses yielded the value 0.651, 12 analyses yielded the value 0.652, and so on. This manner of plotting shows the distribution of all of the results at a glance, and forms the basis of a probability curve, of which the maxima are the most probable values. The effect of more than one major factor may also become apparent and at once suggest a further analysis or break down of the data. This has been done in the present instance by plotting the results obtained by the three major analytical methods both together and separately.

These graphical pictures not only save hours of study of the tabulated data, but actually make the significance of the data so self-evident that lengthy and detailed discussion of each figure is superfluous.

## 2. SPECIFIC GRAVITY CALCULATED FROM THE ANALYSES COMPARED WITH THE KNOWN SPECIFIC GRAVITY

The specific gravity (referred to dry  $\text{CO}_2$ -free air=1) was calculated from the following values given in International Critical Tables, volume 3, page 3, in terms of density.

$\text{CO}_2$ -----	1.5290
$\text{O}_2$ -----	1.1053
$\text{C}_2\text{H}_4$ -----	0.97487
$\text{CO}$ -----	.96713
$\text{H}_2$ -----	.06952
$\text{CH}_4$ -----	.5544
$\text{C}_2\text{H}_6$ -----	1.0493
$\text{N}_2$ -----	0.97208

These data are pictured in figure 1. The correct specific gravity is noted by the dotted line corresponding to the abscissa 0.6475. The measured value was obtained by comparing the weight of the gas with that of an equal volume of dry  $\text{CO}_2$ -free air. The measurements were made by E. C. Creitz at the National Bureau of Standards, who reported a value of  $0.6475_0 \pm 0.00007$  (7 determinations).<sup>3</sup> It will be noted that values obtained by method I (absorption of  $\text{CO}$ ) are generally too high, and are more widely scattered than those of methods II and III. Method III, which it will be remembered takes no account of ethane as such, appears to be the most reproducible; however, only three laboratories (four analysts) reported results obtained with this method, and it is possible that more data would have introduced a greater spread. The average value derived from 99 analyses in series I was  $0.657 \pm 0.007$ ; the average from 96 analyses of series II was 0.648 to .004; the average from 28 analyses of series III was  $0.648 \pm 0.001$ . The plus or minus values indicate reproducibility expressed as the average deviation from the average.

<sup>3</sup> See footnote 2.

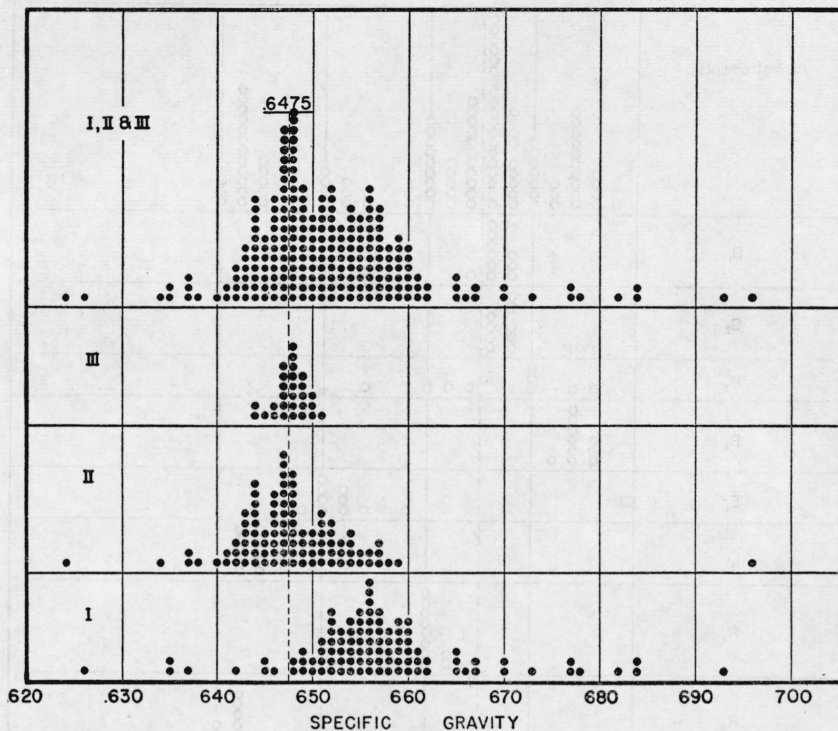


FIGURE 1.

Earlier in the history of Committee D-3, its subcommittee on the determination of specific gravity had discussed this measurement in terms of a tolerance of  $\pm 0.2$  percent. Although this desideratum is met in the average deviation of the 28 analyses by method III, and roughly approached by method II, nevertheless, many separate determinations of these series lie far outside this tolerance. It is accordingly pertinent to compare these calculated results with those obtained by direct measurement of the specific gravity of this standard sample by means of the various instruments actually used for this purpose. This comparison is given in figure 2,<sup>4</sup> although the picture is not complete, as the determinations were all made in one laboratory by three men, and in consequence, the data are probably more compactly grouped than they would have been had 24 laboratories participated. Furthermore, only 10 determinations were made with each instrument. However, an idea of what might have been expected from various laboratories using various instruments may be seen by looking at the top section of figure 2. These data are taken from the original notebook of Smith, Eiseman, and Creitz during their measurements of the specific gravity of sample ASTM D-3-VII-1 by means of 11 different instruments operating on different basic principles. Again, no compliance with a  $\pm 0.2$  percent desideratum is manifest. However, when these data are separated into groups showing the

<sup>4</sup> See footnote 2.

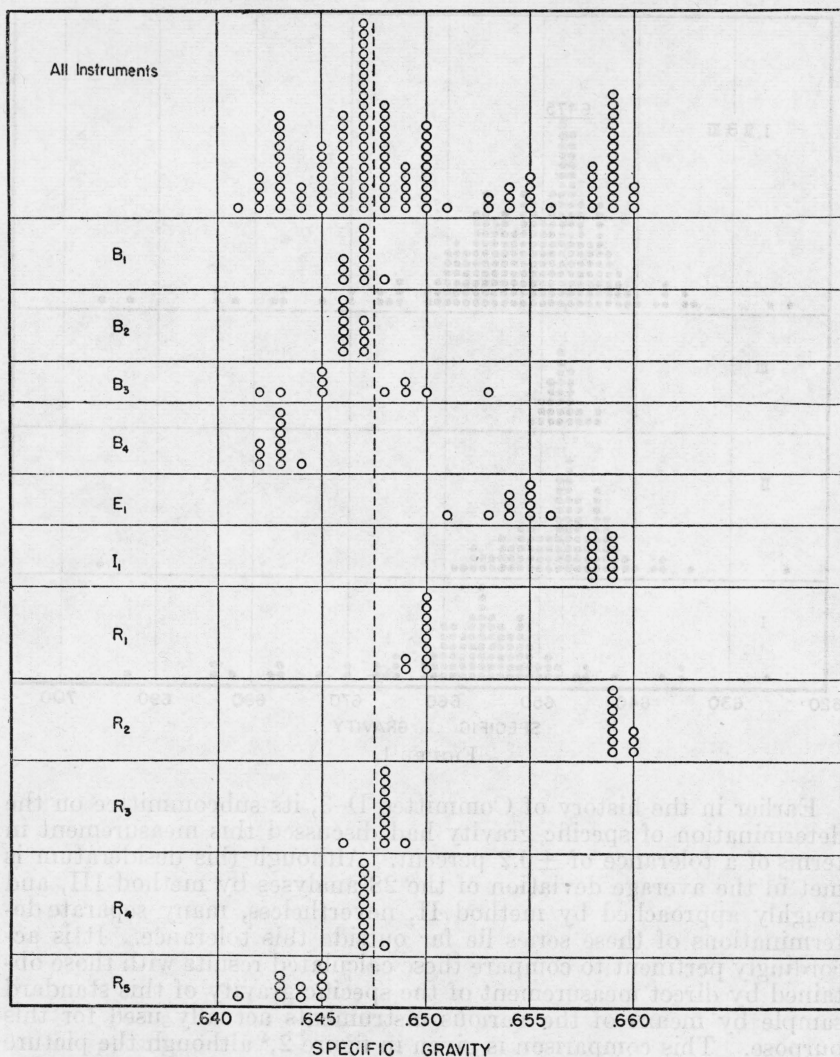


FIGURE 2.

behavior of each instrument, it appears that at least eight instruments give the desired reproducibility (in this instance, 0.001); and of these, four give the desired accuracy insofar as this particular gas sample is concerned. As the same sort of an analysis could be made by separating out the results of various laboratories in the case of the analytical data, we have not added greatly to our store of information other than by saying that certain combinations of the right apparatus, method, and operator can be found, but, in general, the over-all picture demands a more realistic treatment, which, for the present, means a more tolerant tolerance.



### 3. CALCULATED HEATING VALUE COMPARED WITH MEASURED HEATING VALUE

The following measurements of the heating value of the standard sample were made at the National Bureau of Standards. (All values given are in Btu per ft<sup>3</sup> at 60° F, 30 in. Hg.)

(a) During January 1940, J. H. Eiseman obtained these values with the Junker's calorimeter:

549.8  
549.8  
549.5  
548.5

Average-----549.4

(b) During May 1944, R. S. Jessup obtained these values with the Junker's calorimeter:

549.2  
549.1  
548.9  
548.5  
547.5

Average-----548.6

The agreement between these two sets of measurements is good; As previously noted, the lower value obtained in 1944 is in the wrong direction to explain any loss of carbon monoxide by conversion to a carbonyl.

The average of the nine measurements by the Junkers calorimeter is 549.0. This may be taken as representative of the value measured by this instrument when it is carefully operated according to standard procedures and with standard calibration of the meter. The agreement noted is probably better than would have appeared had 24 laboratories made this measurement.

The heating values calculated from all analyses (according to the directions given earlier) are given in figure 3, whereas those for each of the three principal analytical methods are given in figure 4. It will be noted that the greatest frequency of the calculated values appears to be a little to the left of the measured value. The values derived from method I show the greatest scattering and deviation from the measured value. The average value, 532.5, is 16.5 Btu too low. The scattering given by method II is not so bad; and the average value, 545, although 4 Btu low, is much nearer the measured value. The reproducibility yielded by method III is good; and the average value, 546.6, is still closer to the measured value (2.4 Btu low). In connection with method III, it is known in advance that the computed heating value will be in error, as the analysis is calculated as H<sub>2</sub>, CO, and CH<sub>4</sub> only, whereas C<sub>2</sub>H<sub>6</sub> was known to be present. The C<sub>2</sub>H<sub>6</sub> present is calculated as 2CH<sub>4</sub>-H<sub>2</sub>. The heating value of C<sub>2</sub>H<sub>6</sub> is 1759, and that of 2CH<sub>4</sub>-H<sub>2</sub> is only 1675.4. The heating value calculated from such an analysis will accordingly be too low by 0.84 Btu for each 1 percent of C<sub>2</sub>H<sub>6</sub>. If the average value found for C<sub>2</sub>H<sub>6</sub> by the 195 analyses of methods I and II is assumed to be nearly correct, the heating value calculated from method III would be too low by 2.2 Btu. The corrected value, 548.8, is in very comforting agreement with the measured value. Such a correction cannot be made unless

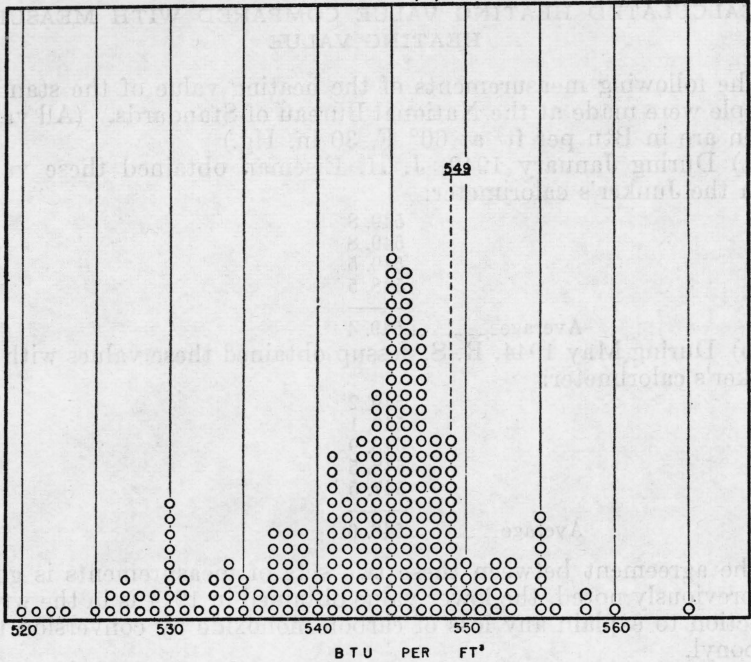


FIGURE 3.

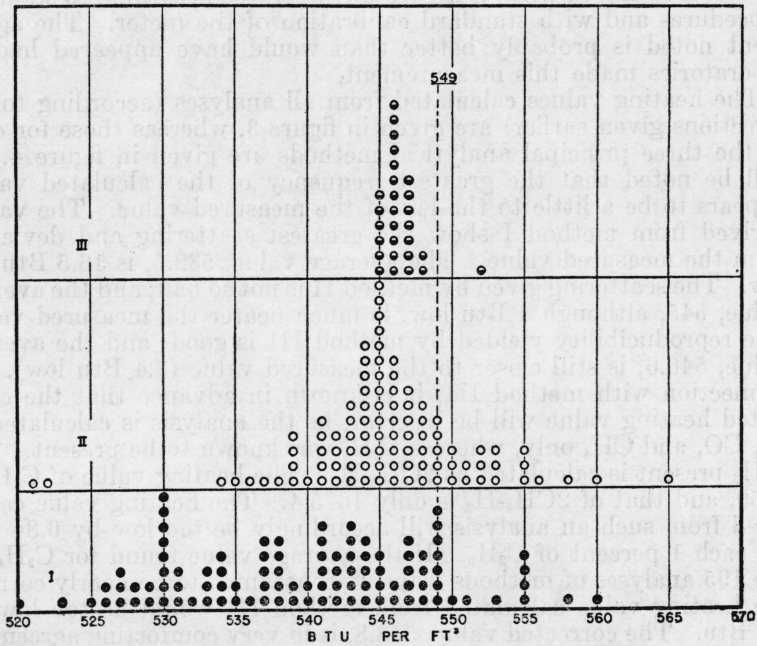


FIGURE 4.

the composition of the sample is known with respect to the heavier hydrocarbons, and if the illuminant fraction of a fuel gas is of complex composition, its heating value must be separately established before the calculated total heating value can be expected to check the measured value.

The latest draft of a proposed standard method for the determination of heating value, under consideration by Subcommittee 3 of ASTM D-3, assigns no tolerance to the measurement, but careful workers hope to obtain values within 0.5 percent of the actual heating value. This would be about 2.7 Btu in the case of the present sample. Method III is within this limit, method II is a little outside, and method I misses the desideratum somewhat.

It is entirely probable that a reproducibility of  $\pm 0.5$  percent may be attained between various laboratories in measuring the heating value of such a sample as this one by the Junker's calorimeter. However, it is interesting to speculate how close this may be to the true heating value. For example, in the present case, other information is available and is confusing:

1. If the meter used in determining the heating values reported is calibrated on open flow at the rate actually used during the calorimetric measurements, the heating value would be 551.2 instead of 549.0.

2. When the heating value was first measured by the Junker's calorimeter, it was also measured by a Thomas recording calorimeter, which in our laboratory is usually in close agreement with the Junker's instrument. The value obtained with the Thomas instrument was 554.

3. The heat of combustion of this sample was measured after it was passed through Ascarite to remove  $\text{CO}_2$  and through anhydrous magnesium perchlorate to remove water vapor. The value obtained by J. W. Knowlton and F. D. Rossini, according to the usual procedures<sup>5</sup>, was  $692,270 \pm 140$  int. j./= mole (44.010 g) of  $\text{CO}_2$  formed. If 1 Btu<sub>ASTM</sub> is taken as equivalent to 1054.538 int. j, the heat of combustion measured is equivalent to 656.47 Btu per mole of  $\text{CO}_2$  formed, which in turn is equivalent to 829.31 Btu/ft<sup>3</sup> of  $\text{CO}_2$  found, referred to the ideal gas state at 0° C and 760 mm Hg (1 mole  $\text{CO}_2$ =22.4146 liters and 1 ft<sup>3</sup>=28.3162 liters).

The late J. R. Branham of this Bureau made a careful volumetric measurement of the  $\text{CO}_2$  produced by the complete combustion of this sample. Corrected for the  $\text{CO}_2$  originally found and for the deviation of  $\text{CO}_2$  from ideality (on the assumption that this deviation was proportional to the existing partial pressure of the  $\text{CO}_2$ ), the stoichiometric relationship found was that 1 volume of gas yielded 0.7020 volume of  $\text{CO}_2$ . From this value and the heat of combustion, it would appear that the heating value of the sample was 542.67 Btu/ft<sup>3</sup>, which is rather low in comparison with the other measurements.<sup>6</sup> On the basis of preliminary measurements of the additive volumes of  $\text{CO}_2$  and the products of combustion, the corrected stoichiometric relation found was that 1 volume of gas yielded 0.7003 volume of  $\text{CO}_2$ , which

<sup>5</sup> Frederick D. Rossini, The heat of formation of water, BS J. Research **6**, 1 (1931) RP259; The heats of combustion of methane and carbon monoxide, BS J. Research **6**, 37 (1931) RP260; The heat of formation of water and the heats of combustion of methane and carbon monoxide. A correction. BS J. Research **7**, 329 (1931) RP343.

<sup>6</sup> At the time the preliminary report of this work was released for study to Committee D-3, the heating value computed from the measured heat of combustion and volumetric measurement of  $\text{CO}_2$  produced was erroneously reported as 553.8 Btu/ft.<sup>3</sup>

in turn gives a computed heating value of 541.35 Btu/ft<sup>3</sup>, still lower than before.

Some time ago it was planned to measure gravimetrically the CO<sub>2</sub> produced from a cubic foot of the sample. This work has never been completed and remains on the after-the-war agenda. Perhaps the matter may be taken care of some day. Until then, it has been worthwhile to know how the results computed from the analyses check with those measured by the instrument most used for direct measurement of the heating value.

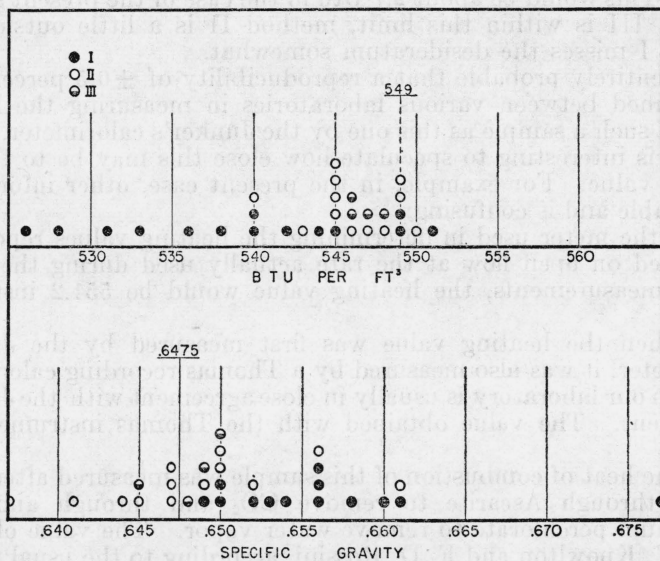


FIGURE 5.

#### 4. COMPARISON OF LABORATORIES

Figure 5 gives an actual comparison of laboratories with respect to the calculation of both heating value and specific gravity. The points are each averages from the laboratories. The symbols of figure 4 are carried over to figure 5; closed circles represent values derived from analyses performed by method I; open circles are corresponding values derived from method II; and half-closed circles are values obtained from method III. The laboratory picture does not seem to alter the pattern already observed with respect to the three methods of analysis.

#### 5. CARBON DIOXIDE

Data for CO<sub>2</sub> are given in figure 6. There are some rogues, but in general these data show very satisfactory reproducibility. Apparently this gas can be determined well enough. The country-wide result was  $4.45 \pm 0.05$  percent. Translated to gravimetric terms, on the basis of the amount of sample used for analysis,  $\pm 0.05$  percent by volume may correspond to as little as 15 micrograms of CO<sub>2</sub>. The volumetric determination which handles such small masses of CO<sub>2</sub>



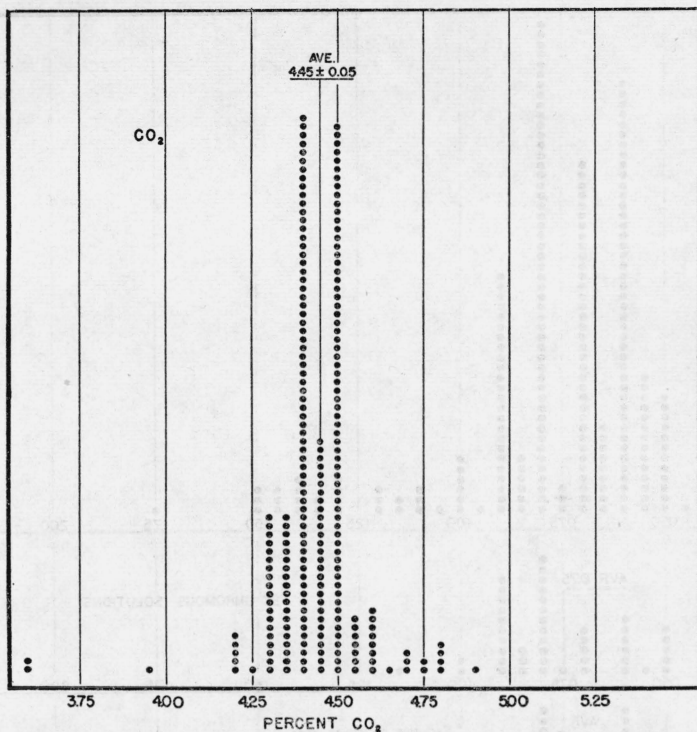


FIGURE 6.

is usually completed in a few minutes. This viewpoint is sometimes overlooked.

#### 6. OXYGEN

The data for O<sub>2</sub> are given in figure 7. All values reported are grouped in the top section of this figure. The middle section gives values determined by chromous solutions, and the bottom section those obtained by alkaline pyrogallol solutions. There is no apparent significant difference between the two reagents as regards this particular gas. The chromous solution might be expected to remove more of the combustible constituents than the pyro solution (by physical solution), but the data available here do not indicate such a result and, therefore, attest the care with which this solution was equilibrated prior to analysis of this sample. The oxygen values in general are more widely scattered than would be expected from good analyses, and the high ones suggest air leakage during delivery to the analytical apparatus. However, there is no apparent correlation between high oxygen and high nitrogen, or between high oxygen and low heating value. As a matter of fact, the general frequency of values higher than expected indicates that something more than such leakage is involved.

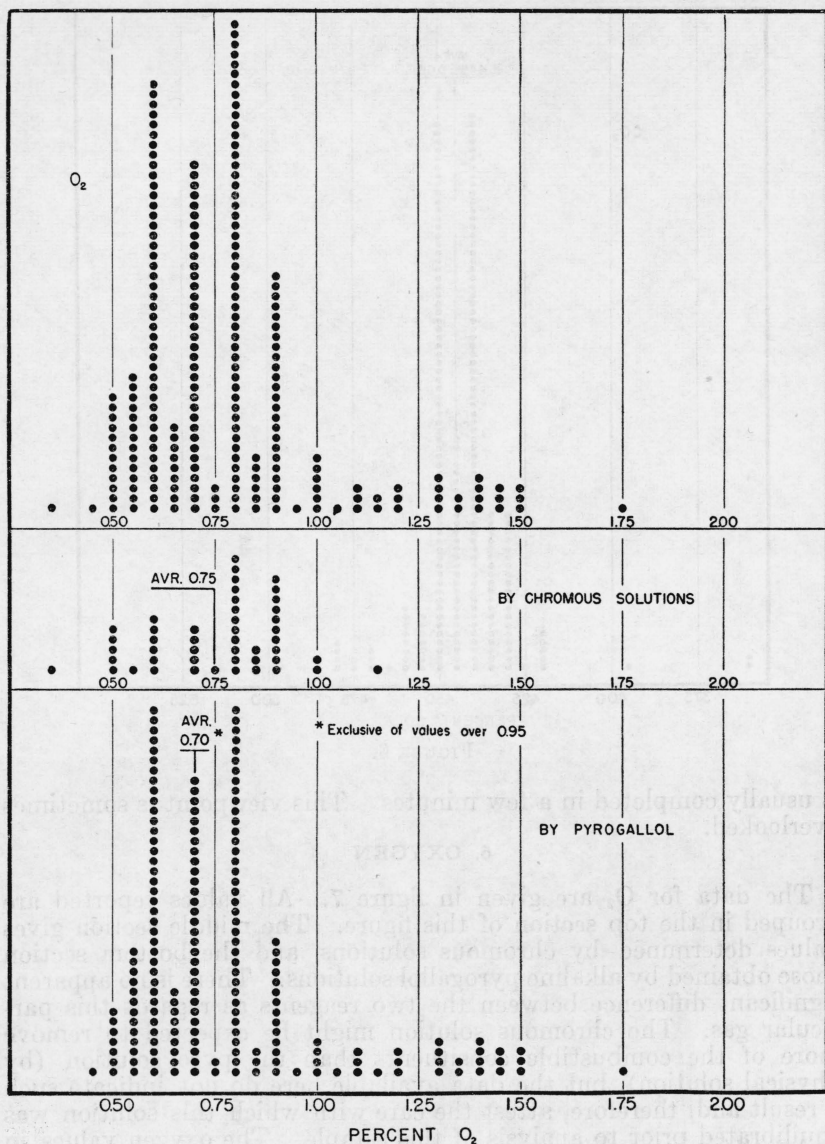


FIGURE 7.

## 7. ETHYLENE

Figure 8 gives the data for ethylene. The top section represents values obtained by reaction with bromine, and the bottom section gives all of the data reported. The effect of the lower values obtained by bromine is notable in the frequency plot of all the data. The values in general are not as widespread as might have been expected.

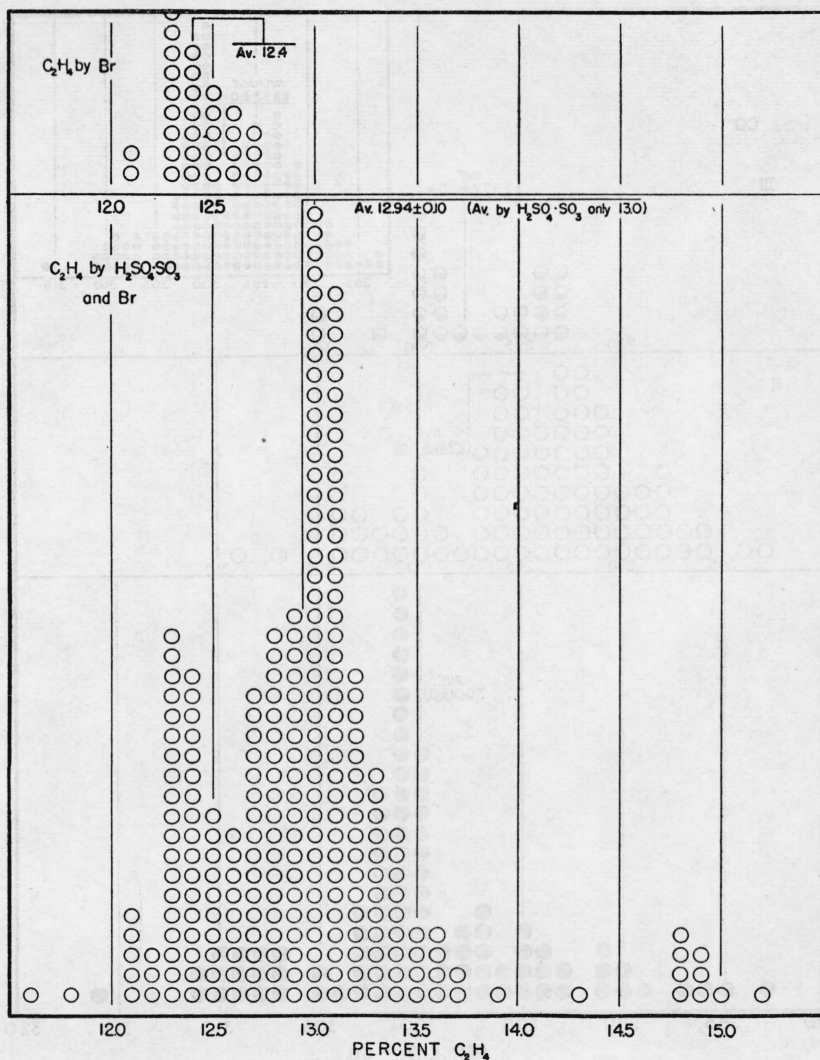


FIGURE 8.

## 8. CARBON MONOXIDE

Data for carbon monoxide are given in figures 9 and 10. The upper right-hand section of figure 9 includes the data from all three methods. The rest of the plot is divided into the three major methods employed. The absorption method shows the best reproducibility, even though it has resulted in the worst reproducibility in the matter of calculating specific gravity and heating value. The average value by absorption is notably higher than those obtained by the two methods of combustion.

Figure 10 is an analysis of the absorption data (method I of figure 9) with respect to the reagent used. The data are insufficient to permit

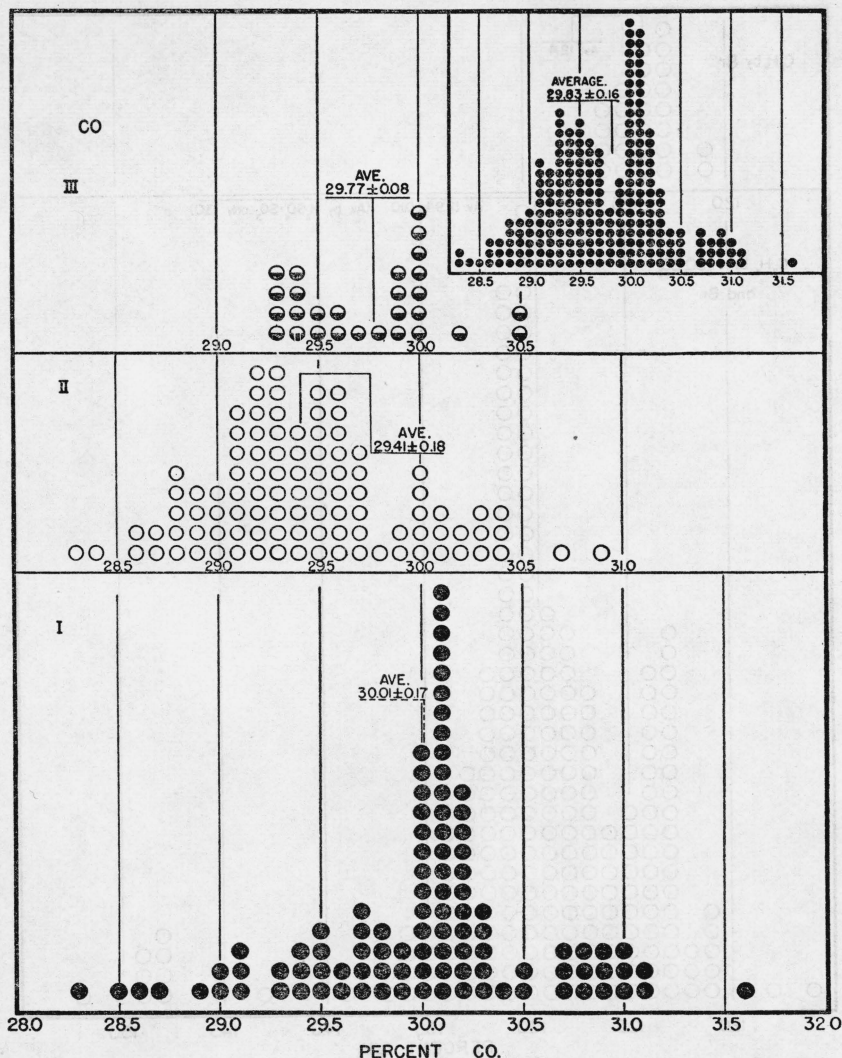


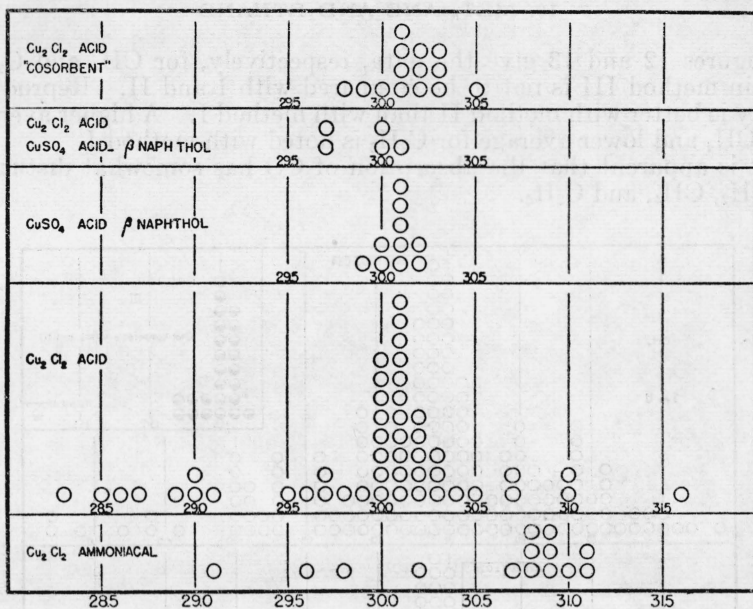
FIGURE 9.

drawing definite conclusions, although the higher values obtained with the ammoniacal reagent are evident.

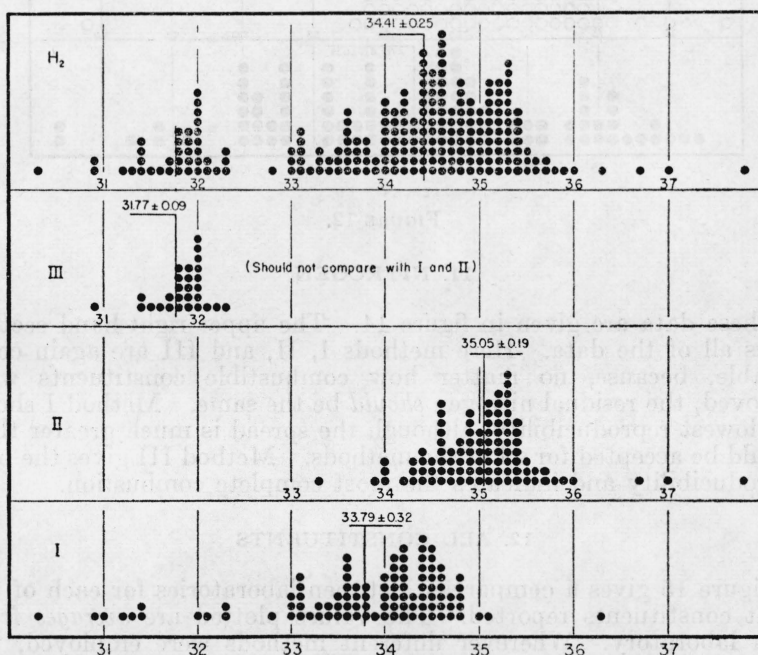
## 9. HYDROGEN

The data for hydrogen are given in figure 11. Method III should not be compared with the other methods for the reasons previously noted. The lower hydrogen obtained with method I is to be compared with the higher CO obtained with this method. Reproducibility is better with method II than with method I.





PERCENT CO  
FIGURE 10.



PERCENT  $\text{H}_2$   
FIGURE 11.

## 10. METHANE AND ETHANE

Figures 12 and 13 give the data, respectively, for  $\text{CH}_4$  and  $\text{C}_2\text{H}_6$ . Again method III is not to be compared with I and II. Reproducibility is better with method II than with method I. A higher average for  $\text{CH}_4$  and lower average for  $\text{C}_2\text{H}_6$  is noted with method I.

It is apparent that the absorption of CO has somewhat disturbed the  $\text{H}_2$ ,  $\text{CH}_4$ , and  $\text{C}_2\text{H}_6$ .

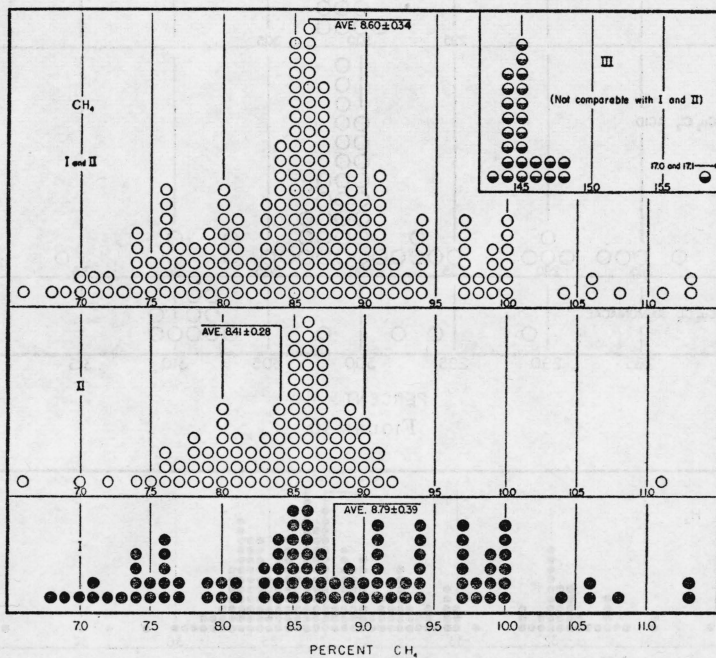


FIGURE 12.

## 11. NITROGEN

These data are given in figure 14. The upper right-hand section gives all of the data. Here methods I, II, and III are again comparable, because, no matter how combustible constituents were removed, the residual nitrogen *should* be the same. Method I shows the lowest reproducibility, although the spread is much greater than should be accepted for all of the methods. Method III gives the best reproducibility and indicates the most complete combustion.

## 12. ALL CONSTITUENTS

Figure 15 gives a comparison between laboratories for each of the eight constituents reported. The values plotted are *averages* from each laboratory. Wherever different methods were employed, the method is indicated by the symbols previously used (see key at top of figure). A greater overlapping of points could be hoped for.

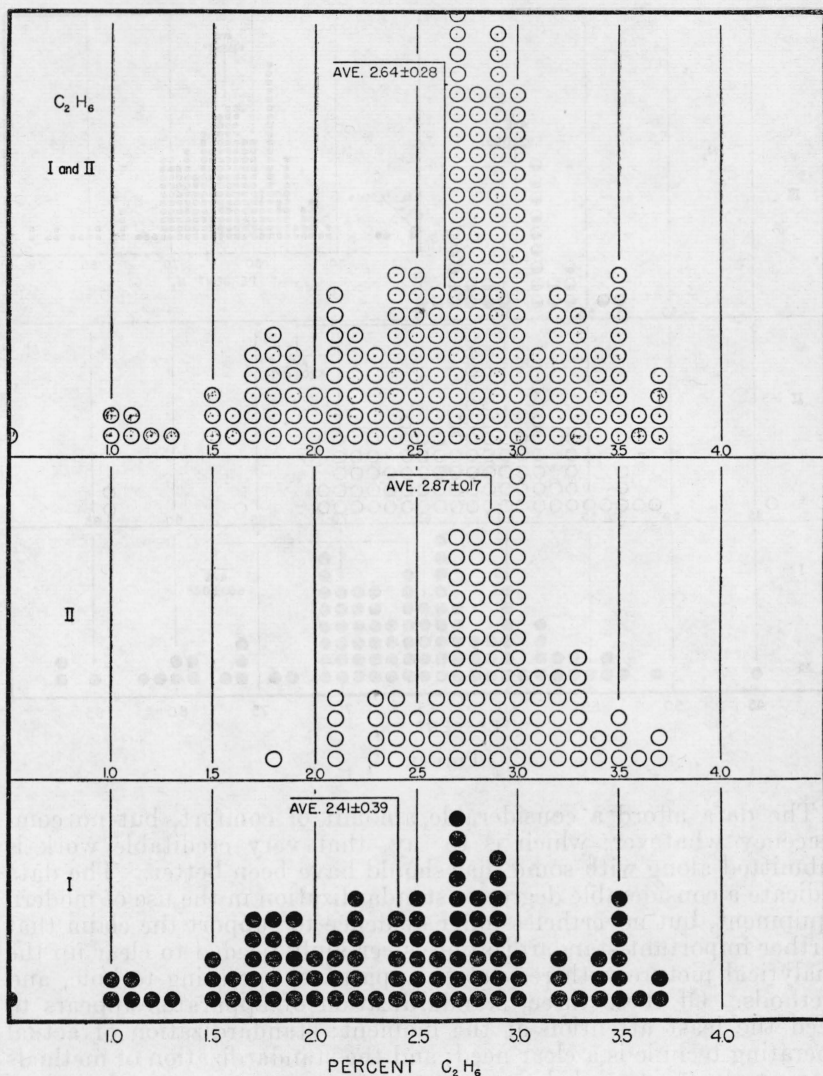


FIGURE 13.

### VIII. CONCLUSIONS

The data here presented give the first clear picture so far available of the actual status of the analysis of a fuel gas of this type in this country. As such they are worthy of some reflection on the part of gas chemists and plant engineers. In view of the considerable effort expended by everyone who took part in the analyses, and because of the importance of the data, the Committee believes that the results should be released for study by all laboratories engaged in this type of volumetric gas analysis, even though the data constitute a preliminary report.

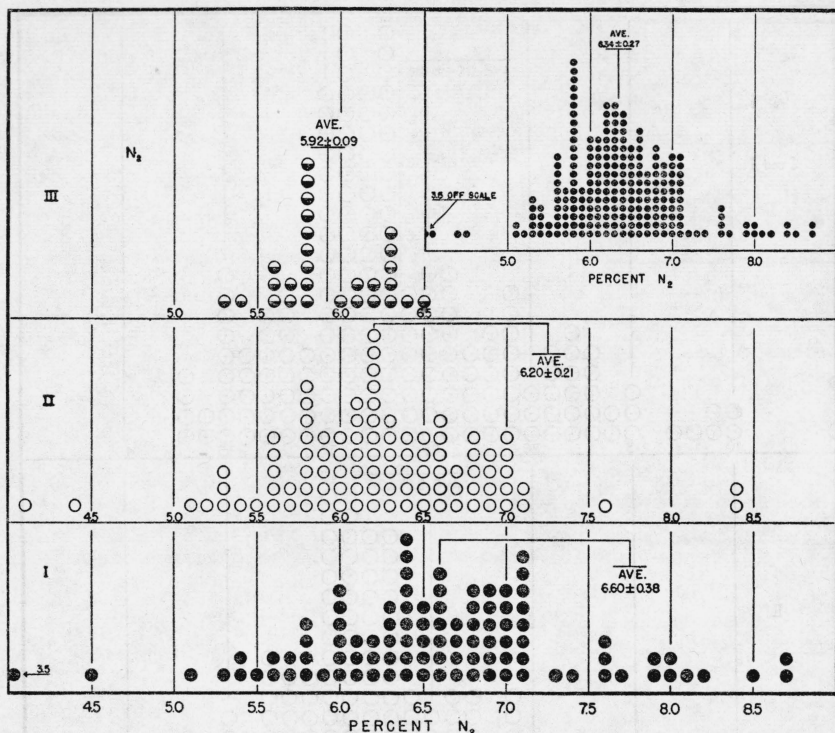


FIGURE 14.

The data afford a considerable amount of comfort, but no complacency whatever; which is to say, that very creditable work is submitted along with some that should have been better. The data indicate a considerable degree of standardization in the use of modern equipment, but nevertheless offer evidence to support the claim that further important standardization is certainly needed to clear up the analytical picture with respect to apparatus, operating technic, and methods. Of these three, standardization of apparatus appears to need the least attention at the moment; standardization of actual operating technic is a clear need; and the standardization of methods seems to be most needed.

#### IX. ADDENDA. A COMPARISON OF RESULTS OBTAINED BY THE MASS SPECTROMETER WITH ANALYSES BY THE CONVENTIONAL VOLUMETRIC METHODS OF ABSORPTION AND COMBUSTION

The mass spectrometer is the most important gas analysis apparatus to be made available during the past few years. It is capable of detecting and estimating an astonishingly large number of components in a mixture highly complex within a remarkably short time. Its scope is exceedingly wide, and it can make separations that would be well nigh impossible by other methods. It is sure to have extensive



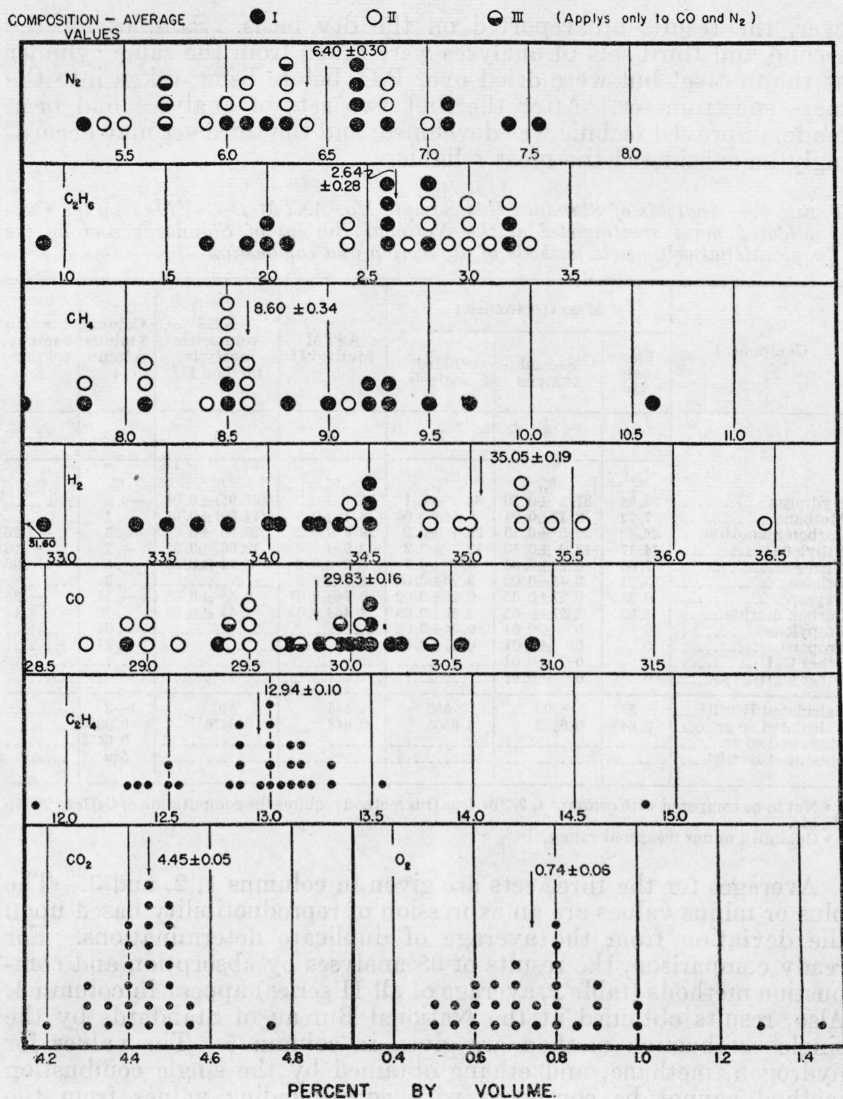


FIGURE 15.

use. For these reasons, it is of considerable interest to compare analyses made by it with those made by the conventional volumetric methods in the case of this nationally analyzed sample.

The analyses by the mass spectrometer are reported in table 4. They were made with the Consolidated Engineering Corporation mass spectrometer at the National Bureau of Standards. The instrument was in charge of A. Keith Brewer, operated by Vernon H. Dibeler, and computations were made by Dorothy I. Thompson. Three sets of analyses were made at different times. The first set was made with the original sample, containing some water vapor; how-

ever, the results are reported on the dry basis. Samples for the second and third sets of analyses were taken from the same cylinder as the first set but were dried over  $P_2O_5$  before being taken into the mass spectrometer. After the first two sets of analyses had been made, improved technic was developed, and the third set may accordingly be considered the most reliable.

TABLE 4.—*Analysis of Standard Gas Sample No. ASTM D-3-VII-1 by the Consolidated mass spectrometer at the National Bureau of Standards and by the conventional volumetric methods of absorption and combustion*

Component	Mass spectrometer			ASTM Method II	NBS volumetric analysis method III	Column 3 minus column 4	Column 3 minus column 5
	First analysis	Second analysis	Third analysis				
	1	2	3	4	5	6	7
	%	%	%	%	%	%	%
Hydrogen.....	36.68	37.1 $\pm 0.20$	34.2 $\pm 0.1$	35.1 $\pm 0.2$	(31.95) $\pm 0.04$	-0.9	-----
Methane.....	7.72	8.17 $\pm 0.04$	8.54 $\pm 0.06$	8.4 $\pm 0.3$	(14.39) $\pm 0.04$	.1	-----
Carbon monoxide.....	25.42	26.5 $\pm 0.10$	29.7 $\pm 0.2$	29.4 $\pm 0.2$	29.96 $\pm 0.03$	.3	-0.26
Ethylene.....	14.17	13.0 $\pm 0.10$	12.7 $\pm 0.2$	12.9 $\pm 0.1$	12.96 $\pm 0.02$	-2.	-26
Nitrogen.....	7.00	6.2 $\pm 0.05$	6.7 $\pm 0.1$	6.2 $\pm 0.2$	5.74 $\pm 0.06$	.5	.96
Ethane.....	3.31	3.43 $\pm 0.02$	3.20 $\pm 0.08$	2.9 $\pm 0.2$	-----	.3	-----
Oxygen.....	0.38	0.27 $\pm 0.05$	0.20 $\pm 0.02$	0.74 $\pm 0.07$	0.55 $\pm 0.03$	-.54	-.35
Carbon dioxide.....	5.33	5.27 $\pm 0.05$	4.55 $\pm 0.08$	4.45 $\pm 0.05$	4.44 $\pm 0.03$	.10	.11
Propylene.....	0	0 $\pm 0.01$	0.04 $\pm 0.02$	-----	-----	.04	-----
Propane.....	0	0 $\pm 0.01$	0.21 $\pm 0.01$	-----	-----	.21	-----
Other $C_2H_4$ .....	0	0 $\pm 0.01$	-----	-----	-----	-----	-----
Other $C_2H_4 + 1$ .....	0	0 $\pm 0.01$	-----	-----	-----	-----	-----
Calculated Btu/ft <sup>3</sup> .....	557	550	552	545	546	b+3	-----
Calculated sp gr.....	0.6406	0.6339	0.6565	0.648	0.6476	b+0.009	-----
Measured sp gr.....	-----	-----	-----	-----	-----	0.6475	-----
Measured Btu/ft <sup>3</sup> .....	-----	-----	-----	-----	-----	549	-----

\* Not to be compared with columns 1, 2, 3 or 4, as this method requires the computation of  $C_2H_4$  as  $2CH_4$ ,  $H_2$ , etc.

b Column 3 minus measured values.

Averages for the three sets are given in columns 1, 2, and 3. The plus or minus values are an expression of reproductibility based upon the deviation from the average of duplicate determinations. For ready comparison, the results of 98 analyses by absorption and combustion methods (table 2, average of all II series) appear in column 4. Also, results obtained at the National Bureau of Standards by the single combustion method are given in column 5. The values for hydrogen, methane, and ethane obtained by the single combustion method cannot be compared with corresponding values from the other methods, as all of the combustible gases (except ethylene and homologues) are computed as  $H_2$ ,  $CO$ , and  $CH_4$ . Thus  $C_2H_6$  is computed as  $2CH_4 - H_2$ ,  $C_3H_8$  as  $3CH_4 - 2H_2$ , and so on. However, the values so obtained can be used in computing heating value and specific gravity and in studying combustion characteristics.

The three sets of analyses by the mass spectrometer, which were made at various times during 1944, differ among themselves by as much as 3 or 4 percent in some instances. The first analysis yielded a calculated heating value 8 Btu higher than the measured value and a calculated specific gravity 0.007 below the measured value. The second analysis gave a calculated heating value only 1 Btu higher than the measured value, but a specific gravity 0.013 lower than the



TABLE 2.—Analysis of Standard Gas Sample ASTM D-3-VII-1, (carburetted water-gas type)

Condensed table giving average values of 288 analyses by different apparatus and methods. The specific gravity of this gas was measured by E. O. Creitz at the National Bureau of Standards. The measured value was  $0.64750 \pm 0.00007$ . The heating value was measured independently by J. H. Eiseman and Ralph S. Jessup with the Junker's calorimeter at the National Bureau of Standards. The measured value was  $549.0 \pm 0.6$  Btu/ft<sup>3</sup>.

Condensed key to methods of analysis:

- I. CO by absorption, H<sub>2</sub> by CuO, CH<sub>4</sub>+C<sub>2</sub>H<sub>6</sub> by slow combustion.  
 II. CO+H<sub>2</sub> by CuO, CH<sub>4</sub>+C<sub>2</sub>H<sub>6</sub> as in II.  
 III. CO+H<sub>2</sub>+CH<sub>4</sub>+heavier C<sub>n</sub>H<sub>2n+2</sub> by slow combustion, calculated as CO+H<sub>2</sub>+CH<sub>4</sub> only.

First set of arabic numerals: 1-, O<sub>2</sub> by pyro; 2-, O<sub>2</sub> by chromous solution.  
 Second set of arabic numerals: 1-, C<sub>2</sub>H<sub>4</sub> by H<sub>2</sub>SO<sub>4</sub>SO; 2-, C<sub>2</sub>H<sub>4</sub> by bromine.

Key to apparatus:

- V<sub>1</sub>—Equipped with pressure-temperature compensator.  
 V<sub>2</sub>—Volumes corrected for temperature-pressure changes.  
 V<sub>3</sub>—Volumes not corrected for temperature-pressure changes.  
 V<sub>4</sub>—Constant volume apparatus.  
 R<sub>1</sub>—Pipettes connected to burette by manifold.  
 R<sub>2</sub>—Single pipette connected to burette.  
 R<sub>3</sub>—Pipettes separate from burette.  
 The last symbol designates the confining fluid.

Line	Laboratory	Method	Apparatus	Carbon dioxide					Oxygen					Ethylene					Carbon monoxide					Hydrogen					Methane					Ethane					Nitrogen					Btu/ft <sup>3</sup> —60°, 30 in. Hg. Sat.					Specific gravity				
				Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Amount	Average deviation	Max	Min	Number of determinations	Btu/ft <sup>3</sup>	Average deviation	Max	Min	Number of determinations	Specific gravity	Average deviation	Max	Min					
1	1	I-1-1	V <sub>1</sub> R <sub>1</sub> Hg	7	4.46	±0.03	4.50	4.35	7	0.68	±0.04	0.75	0.60	7	12.84	±0.06	12.90	12.70	7	30.19	±0.10	30.30	30.10	7	33.63	±0.10	33.75	33.50	7	2.59	±0.12	2.80	2.35	7	6.85	±0.19	7.10	6.45	7	540	±3	543	537	7	0.656	±0.002	0.659	0.652					
2	2	I-1-1	V <sub>1</sub> R <sub>1</sub> H <sub>2</sub> O acid	3	4.35	±0.03	4.40	4.30	3	.92	±0.08	1.05	.80	3	13.08	±0.04	13.10	13.00	3	29.93	±0.19	30.15	29.65	3	33.98	±0.26	34.20	33.60	3	9.22	±0.44	9.70	8.55	3	6.63	±0.24	7.00	6.40	3	536	±2	538	533	3	.652	±0.002	.654	.650					
3	7	I-1-1	V <sub>1</sub> R <sub>1</sub> Hg	4	4.19	±0.12	4.3	3.96	4	.98	±0.09	1.15	.84	4	12.83	±0.10	12.98	12.7	4	29.70	±0.41	30.17	29.13	4	34.50	±0.29	34.03	32.99	4	16.59	±0.37	11.32	10	4	7.33	±0.56	8.19	6.32	4	526	±3	530	520	4	.650	±0.004	.655	.642					
4	8	I-1-1	V <sub>1</sub> R <sub>1</sub> Hg	10	4.43	±0.06	4.5	4.3	10	.66	±0.06	0.80	.60	10	13.21	±0.09	13.4	13.0	10	30.08	±0.07	30.2	29.9	10	34.5	±0.20	34.8	34.2	10	7.8	±0.6	9.0	6.9	10	6.2	±0.35	7.1	5.6	10	549	±2	555	548	10	.656	±0.006	.670	.651					
5	12	I-1-1	V <sub>1</sub> R <sub>1</sub> Hg	10	4.44	±0.04	4.52	4.33	10	.80	±0.02	.82	.72	10	13.10	±0.07	13.27	12.97	10	30.53	±0.45	31.55	29.71	10	34.03	±0.75	36.25	33.07	10	9.33	±0.88	10.75	7.48	10	6.30	±0.97	7.35	4.53	10	533	±3	541	526	10	.650	±0.010	.667	.626					
6	15	I-1-1	V <sub>1</sub> R <sub>1</sub> Hg	6	4.48	±0.06	4.6	4.4	6	.71	±0.08	.9	.6	6	12.98	±0.09	13.1	12.8	6	30.10	±0.10	30.3	29.9	6	34.35	±0.30	34.8	33.7	6	9.5	±1.4	11.3	6.8	4	5.3	±0.9	6.6	3.5	4	551	±4	558	547	4	.649	±0.006	.659	.637					
7	23	I-1-1	V <sub>2</sub> R <sub>1</sub> Hg	10	4.77	±0.04	4.91	4.70	10	1.46	±0.08	1.77	1.36	10	14.84	±0.15	15.21	14.26	10	28.92	±0.32	29.61	28.25	10	31.58	±0.73	34.29	30.91	10	9.18	±0.45	9.97	8.33	10	7.55	±0.79	8.72	5.36	10	549	±4	560	538	10	.677	±0.007	.693	.652					
Average of I-1-1 series				50	4.49	±0.05			40	0.76	±0.05			50	13.40	±0.09			50	29.92	±0.24			50	33.57	±0.42			48	9.01	±0.60			48	6.64	±0.58			48	541.8	±3			48	0.6577	±0.006							
8	4	I-2-1	V <sub>1</sub> R <sub>1</sub> Hg	7	4.5	±0.04	4.6	4.3	7	0.9	±0.09	1.0	0.7	7	13.0	±0.04	13.1	13.0	7	30.1	±0.19	30.5	29.8	7	34.3	±0.27	35.0	34.1	7	2.6	±0.10	2.8	2.5	7	6.0	±0.29	6.5	5.3	7	541.5	±2	547	541	7	0.653	±0.003	0.656	0.648					
9	6	I-2-1	V <sub>1</sub> R <sub>1</sub> Hg	5	4.54	±0.03	4.6	4.5	5	.88	±0.06	1.0	.8	5	13.29	±0.11	13.45	13.10	5	29.87	±0.14	30.05	29.65	5	33.79	±0.21	34.00	33.45	5	8.48	±0.10	8.7	8.3	5	6.56	±0.19	6.85	6.35	5	544	±2	546	541	5	.658	±0.002	.661	.656					
10	17	I-2-1	V <sub>1</sub> R <sub>1</sub> Hg	10	4.54	±0.06	4.65	4.43	10	.80	±0.03	0.9	.7	10	13.56	±0.10	13.85	13.35	10	29.36	±0.11	29.55	29.10	10	32.91	±0.26	33.30	32.28	10	9.72	±0.23	10.01	9.35	10	7.11	±0.27	7.67	6.70	10	545	±2	549	542	10	.661	±0.002	.667	.658					
Average of I-2-1 series				22	4.53	±0.05			22	0.85	±0.06			22	13.32	±0.08			22	29.71	±0.15			22	33.55	±0.25			22	9.05	±0.15			22	6.63	±0.26			22	544	±2			22	0.6578	±0.002							
11	2	I-1-2	V <sub>1</sub> R <sub>1</sub> H <sub>2</sub> O acid	7	4.32	±0.06	4.40	4.20	7	0.99	±0.10	1.10	0.80	7	12.52	±0.13	12.65	12.55	7	30.04	±0.10	30.25	29.80	7	34.19	±0.23	34.70	33.75	7	9.32	±0.34	9.75	8.80	7	6.64	±0.16	6.95	6.25	7	531	±4	532	527	7	0.650	±0.002	0.653	0.646					
12	19	I-1-2	V <sub>2</sub> R <sub>1</sub> H <sub>2</sub> O salt	10	4.46	±0.03	4.50	4.40	10	.80	±0.07	0.90	.70	10	12.33	±0.08	12.50	12.11	10	30.91	±0.11	31.10	30.72	10	34.50	±0.13	34.80	34.23	10	7.47	±0.19	8.03	7.10	10	6.69	±0.13	7.07	6.40	10	528	±2	531	523	10	.656	±0.001	.660	.654					
13	22	I-1-2	V <sub>1</sub> R <sub>1</sub> Hg	10	4.38	±0.05	4.5	4.2	10	1.29	±0.09	1.5	1.0	10	12.38	±0.08	12.5	12.3	10	30.11	±0.09	30.3	30.0	10	34.48	±0.21	34.8	34.1	10	8.11	±0.29	8.6	7.6	10	6.10	±0.14	6.4	5.8	10	538	±3	544	533	10	.654	±0.002	.658	.651					
Average of I-1-2 series				27	4.39	±0.05			17	0.88	±0.08			27	12.40	±0.10			27	30.39	±0.10			27	34.41	±0.19			27	8.19	±0.27			27	6.46	±0.14			27	532.5	±3			27	0.6537	±0.002							
14	20	I-2-2	Bone-Wheeler	2	4.31	±0.05			2	0.75	±0.07			2	12.52	±0.05			2	30.24	±0.07			2	33.34	±0.01			2	8.97	±0.05			2	2.80				2	7.07	±0.005			2	539.6	±0.6			2	0.6597	±0.0003		
Average of all I series				101	4.47	±0.05			81	0.81	±0.06			101	12.97	±0.09			101	30.01	±0.17			101	33.75	±0.32			99	8.79	±0.39			99	2.41	±0.39			99	6.60	±0.38			99	538.7	±2.8			99	0.6567	±0.004		
15	1	II-1-1	V <sub>1</sub> R <sub>1</sub> Hg	9	4.42	±0.03	4.50	4.40	9	0.75	±0.08	0.85	0.60	9	12.83	±0.05	13.00	12.70	9	29.16	±0.07	29.30	29.00	9	35.27	±0.06	35.35	35.10	9	8.59	±0.10	8.75	8.40	9	2.87	±0.08	3.00	2.80	9	6.12	±0.08	6.30	6.00	9	545	±1	547	544	9	0.644	±0.002	0.654	0.640
16	3	II-1-1	V <sub>2</sub> or V <sub>1</sub> R <sub>1</sub> Hg	10	4.5	±0.02	4.5	4.4	10	.8	±0.03	.9	.6	10	13.0	±0.11	13.4	12.8	10	29.9	±0.20	29.6	29.2	10	34.4	±0.15	34.6	34.0	10	8.1	±0.41	8.9	7.2	10	3.1	±0.15	3.5	2.8	10	6.3	±0.23	6.8	5.8	10	546	±2	555	543	10	.656	±0.002	.659	.651
17	9	II-1-1	V <sub>1</sub> R <sub>1</sub> Hg	8	4.42	±0.07	4.5	4.3	8	.68	±0.08	.8	.6	8	13.28	±0.11	13.5	13.2	8	29.41	±0.06	29.5	29.3	8	34.8	±0.10	34.9	34.6	8	8.6	±0.30	9.0	8.1	8	2.4	±0.20	2.7	2.1	8	6.4	±0.30	6.8	5.2	8	545	±4	555	539	8	.649	±0.002	.652	.647
18	10	II-1-1	V <sub>1</sub> R <sub>1</sub> Hg	9	4.45	±0.08	4.52	4.31	10	.62	±0.06	.69	.51	10	13.05	±0.09	13.53	12.76	10	29.63	±0.39	30.74	28.65	10	34.82	±0.35	34.75	33.93	10	8.07	±0.38	9.03	7.71	10	3.20	±0.21	3.68	2.74	10	6.29	±0.34	7.12	5.57	10	549	±6	560	538	10	.650	±0.003	.656	.646
19	13	II-1-1	V <sub>1</sub> R <sub>1</sub> Hg	10	4.44	±0.06	4.4	4.2	10	.78	±0.07	.9	.6	10	13.1																																						



measured value. However, the third analysis is in reasonable agreement with the volumetric chemical analyses by the conventional methods, with differences varying from 0.1 to about 1 percent among the various components. These differences are noted in columns 6 and 7. The heating value calculated from the third analysis by the spectrometer was 3 Btu higher than the measured value, whereas that computed from the chemical methods was 3 or 4 Btu lower. The computed specific gravity by the spectrometer was 0.6565, as compared with 0.6476 and 0.648 by the chemical methods, and  $0.6475 \pm 0.00007$  by direct measurement. This index of composition favors the chemical methods, which is strange in view of the fact that it is known they are not capable of yielding the complete composition of such a mixture, whereas the mass spectrometer presumably is.

It will be noted that propylene and propane were identified in the third spectrometer series, whereas these constituents were not found in the first two. All of these samples were taken from the same cylinder where the standard mixture is stored under pressure and could be certified to be of uniform composition, except for minor changes which might occur by prolonged contact with phosphoric acids formed on the  $P_2O_5$  used for drying. If such reactions had occurred, the first sample, which was not passed over  $P_2O_5$ , should have contained propylene in the greatest amount; but no propylene was identified in this sample, nor in the succeeding dried sample, whereas the third sample, also dried, contained 0.04 percent. It would be difficult to lose 0.21 percent of propane in a quick passage of the sample over  $P_2O_5$ , yet this amount appears in one dried sample and none was found in the other dried sample, or in the undried sample. There is no reason to suppose that the three successive portions withdrawn from the cylinder and delivered, either through  $P_2O_5$  or not, were not all of the same composition to well within the significance represented by the resolution of the spectrometer itself.

If the third analysis employing improved technics is accepted as correct, it will be interesting to compute what errors were made in computing the heating value from the analytical data derived from the chemical methods. If the sample actually contained 0.04 percent of propylene, all of the computed heating values from absorption analyses would have been 0.3 Btu too low. Also, if the sample contained 0.21 percent of propane, the combustion analyses would have yielded a computed heating value 0.3 Btu too low. Together, these errors would total 0.6 Btu—not enough to explain the general low average noted. If the sample contained 3.2 percent of ethane, the heating value computed from combustion analyses (method III) would have been 2.7 Btu too low. For the NBS analyses, the heating value computed was 546 Btu. Corrected for ethane, propane, and propylene found by the mass spectrometer (third series of analyses), this value would be changed to 549.3, to agree with the measured value (Junker's).



TABLE 3.—*Analysis of Standard Gas Sample ASTM D-3-VII-1 (carburetted water-gas type)*

[Complete report of the 24 cooperating laboratories. The starred values are omitted from the averages.]

Lab- oratory No.	Apparatus	Method	Anal- ysis No.	CO <sub>2</sub>	O <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	N <sub>2</sub>	Total	Btu/ft <sup>3</sup>	Specific gravity	As reported by laboratories <sup>1</sup>	
															Btu	sp gr
1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	V <sub>1</sub> R <sub>1</sub> Hg----- Burrell (0.17).	II-1-1	1	% Min	% Min	%	%	%	%	%	%	%	546	0.643		
			2	4.45	.65	12.85	29.20	35.35 Max	8.60	2.90	6.10	-----	547	.654 Max		
			3	4.40	.85 Max	13.00 Max	29.10	35.10 Min	8.40 Min	3.00 Max	6.30 Max	-----	547 Max	.654 Max		
			4	4.40	.75	12.85	29.10	35.25	8.65	2.85	6.20	-----	542 Min	.644		
			5	4.45	.80	12.85	29.20	35.30	8.65	2.90	6.05	-----	547	.644		
			6	4.50 Max	.80	12.85	29.20	35.30	8.65	2.80	6.05	-----	544	.644		
			7	4.40	.85	12.80	29.20	35.30	8.40	3.00	6.00 Min	-----	545	.645		
			8	4.40	.80	12.80	29.00 Min	35.30	8.70	2.80	6.15	-----	544	.642		
			9	4.40	.80	12.80	29.10	35.25	8.55	2.90	6.20	-----	545	.644		
			9	4.40	.65	12.80	29.30 Max	35.35	8.75 Max	2.70 Min	6.05	-----	544	.640 Min		
			Avg.	4.42±0.03	0.75±0.08	12.83±0.05	29.16±0.07	35.27±0.06	8.59±0.10	2.87±0.08	6.12±0.08	-----	545±1.2	0.644±0.002		
		I-1-1	1	4.35 Min	0.65	12.90 Max	30.30 Max	33.50 Min	8.90	2.35 Min	7.05	-----	538	0.652 Min		
			2	4.45	.75 Max	12.70 Min	30.30	33.50	8.60 Min	2.60	7.10 Max	-----	537 Min	.659 Max		
			3	4.40	.70	12.85	30.10 Min	33.70	8.70	2.60	7.00	-----	538	.657		
			4	4.50 Max	.65	12.90	30.10	33.75 Max	8.80	2.70	6.60	-----	543 Max	.656		
			5	4.45	.60 Min	12.85	30.10	33.75	8.60	2.80 Max	6.85	-----	542	.657		
			6	4.50	.70	12.75	30.10	33.65	8.70	2.70	6.90	-----	539	.658		
			7	4.50	.70	12.90	30.30	33.55	9.10 Max	2.50	6.45 Min	-----	543	.656		
			Avg.	4.46±0.03	0.68±0.04	12.84±0.06	30.19±0.10	33.63±0.10	8.77±0.14	2.59±0.12	6.85±0.19	-----	540±3	0.656±0.002		
		I-1-2	1	4.35	0.90	12.55	30.05	34.20	9.10	2.10	6.75	-----	531.1	0.651	540.5	
			2	4.35	1.00	12.65	30.10	33.75 Min	9.70	1.70 Min	6.75	-----	530.3	.653 Max	539.7	
			3	4.35	1.10 Max	12.60	30.05	33.85	9.75 Max	1.70	6.60	-----	530.2	.651	539.6	
			4	4.35	1.10	12.50	29.80 Min	34.20	9.70	1.75	6.60	-----	529.3	.649	538.7	
			5	4.40 Max	1.10	12.55	29.95	34.20	9.10	2.15	6.55	-----	531.7	.652	541.0	
			6	4.20 Min	.90	12.10 Min	30.25 Max	34.45	8.80 Min	2.35 Max	6.95 Max	-----	526.7 Min	.650	545.5	
			7	4.25	.80 Min	12.70 Max	30.10	34.70 Max	9.10	2.10	6.25 Min	-----	535.1 Max	.646 Min	544.7	
			Avg.	4.32±0.06	0.99±0.10	12.52±0.13	30.04±0.10	34.19±0.23	9.32±0.34	1.98±0.23	6.64±0.16	-----	530.7±0.4	0.650±0.002	541.4	
2	V <sub>1</sub> R <sub>1</sub> H <sub>2</sub> O----- Elliott-Bur- rell (0.04)	I-1-1	8	4.30 Min	0.80 Min	13.10 Max	30.00	34.15	9.40	1.75	6.50	-----	536.4	0.650 Min	545.8	
			9	4.35	1.05 Max	13.10	29.65 Min	33.80 Min	9.70 Max	1.65 Min	7.00 Max	-----	532.9 Min	.654 Max	542.3	
			10	4.40 Max	.90	13.00 Min	30.15 Max	34.20 Max	8.55 Min	2.40 Max	6.40 Min	-----	538.3 Max	.653	547.8	
			Avg.	4.35±0.03	0.92±0.08	13.08±0.04	29.93±0.19	33.98±0.26	9.22±0.44	1.90±0.33	6.63±0.24	-----	536.1±2	0.652±0.002	545.2	
		I-1-1	11	4.30	0.95	12.95	29.70	33.90	8.60	2.40	7.20	-----	535.7	0.656	545.1	

3	$\left\{ \begin{array}{l} V_{2-3}R_1Hg \\ U. S. Steel- \\ Burrell-Mod- \\ ified (0.12) \end{array} \right\}$	II-1-1	1	4.4 Min	0.8	12.9	30.1	34.3	7.8	3.3	6.4	-----	545.0	0.657	-----	-----
			2	4.5 Max	.8	12.8 Min	30.0	34.6 Max	8.0	3.1	6.2	-----	542.7 Min	.654	-----	-----
4	$\left\{ \begin{array}{l} V_1R_1Hg \\ Burrell-U. S \\ Steel (0.70) \end{array} \right\}$	II-2-1	3	4.5	.8	13.2	30.2 Max	34.5	7.9	3.1	5.8 Min	-----	548.5	.655	-----	-----
			4	4.5	.6 Min	13.4 Max	30.1	34.6	7.2 Min	3.5 Max	6.1	-----	551.7	.657	-----	-----
			5	4.4	.9 Max	12.8	29.6 Min	34.4	8.9 Max	2.8 Min	6.2	-----	554.7 Max	.651 Min	-----	-----
			6	4.5	.8	13.0	29.6	34.4	8.9	2.8	6.0	-----	547.9	.652	-----	-----
			7	4.5	.8	13.0	30.0	34.4	8.0	3.1	6.2	-----	545.3	.655	-----	-----
			8	4.5	.8	13.0	29.7	34.0 Min	8.0	3.2	6.8 Max	-----	544.9	.659 Max	-----	-----
			9	4.5	.8	13.0	29.7	34.0	8.3	3.0	6.7	-----	544.4	.658	-----	-----
			10	4.5	.8	13.0	30.0	34.3	7.9	3.2	6.3	-----	545.8	.657	-----	-----
			Avg.	4.5±0.02	0.8±0.03	13.0±0.11	29.9±0.20	34.4±0.15	8.1±0.41	3.1±0.15	6.3±0.23	-----	546.0±2	0.656±0.002	555.4	-----
			1	4.5 Max	0.8	12.9 Min	29.6 Max	35.1 Max	8.4	2.9	5.8	-----	545.2	0.6475	555	-----
5	$\left\{ \begin{array}{l} V_1R_1Hg \\ Burrell-U. S \\ Steel (0.70) \end{array} \right\}$	II-2-1	2	4.5	.7 Min	13.0	29.6	34.9 Min	9.0 Max	2.5 Min	5.8	-----	545.2	.6453 Min	555	-----
			3	4.5	.9 Max	13.0	29.6	34.9	8.3 Min	3.0 Max	5.8	-----	547.0	.6499 Max	557	-----
			4	4.4	.9	13.1 Max	29.5	34.9	8.7	2.9	5.6 Min	-----	550.4 Max	.6475	560	-----
			5	4.3 Min	.9	13.1	29.4	35.0	8.6	2.7	6.0	-----	545.9	.6462	556	-----
			6	4.5	.9	13.1	29.1 Min	35.1	8.5	2.6	6.2 Max	-----	542.5 Min.	.6469	552	-----
			7	4.5	.8	13.1	29.6	34.9	8.6	2.6	5.9	-----	544.5	.6483	555	-----
			8	4.4	.8	13.0	29.6	35.0	8.6	2.7	5.9	-----	545.0	.6468	555	-----
			Avg.	4.5±0.05	0.8±0.06	13.0±0.06	29.5±0.12	35.0±0.08	8.6±0.14	2.7±0.14	5.9±0.12	-----	544.6±2	0.6473±0.001	555.6	-----
			1	4.5	0.8	13.0 Min	30.5 Max	34.1 Min	8.4 Min	2.7	6.0	-----	542.9	0.6562 Max	552	-----
			2	4.5	.9	13.1 Max	30.2	34.1	8.5	2.6	6.1	-----	542.8	.6559	552	-----
5	$\left\{ \begin{array}{l} V_1R_1Hg \\ Shepherd \\ (0.03) \end{array} \right\}$	III-1-1	3	4.5	.7 Min	13.0	30.2	34.1	8.7 Max	2.5 Min	6.3	-----	541.5	.6546	551	-----
			4	4.5	.8	13.0	30.2	34.1	8.5	2.7	6.2	-----	543.0	.6553	553	-----
			5	4.3 Min	1.0 Max	13.1	29.9	34.1	8.6	2.5	6.5 Max	-----	541.1 Min	.6545	551	-----
			6	4.6 Max	0.9	13.1	29.8 Min	35.0 Max	8.6	2.7	5.3 Min	-----	547.2 Max	.6479 Min	557	-----
			7	4.5	.9	13.0	30.0	34.5	8.5	2.8 Max	5.8	-----	545.4	.6524	555	-----
			Avg.	4.5±0.04	0.9±0.09	13.0±0.04	30.1±0.19	34.3±0.27	8.5±0.07	2.6±0.10	6.0±0.29	-----	541.5±2	0.6530±0.003	553	-----
			1	4.39	0.65	13.09	29.35	31.71	14.48	-----	6.33	100.00	546	0.649	-----	-----
			2	4.39	.66	13.08	29.45	31.61 Min	14.51	-----	6.30	100.00	546	.650 Max	-----	-----
			3	4.38	.69 Max	13.04	29.42	31.72	14.39 Min	-----	6.36 Max	100.00	545 Min	.650	-----	-----
			4	4.40	.64	13.11	29.34	31.83	14.46	-----	6.22	100.00	547	.648	-----	-----
5	$\left\{ \begin{array}{l} V_1R_1Hg \\ Shepherd \\ (0.03) \end{array} \right\}$	III-1-1	5	4.41	.61	13.00 Min	29.44	31.87	14.48	-----	6.20	100.01 Max	546	.648	-----	-----
			6	4.37	.59	13.00	29.59 Max	31.76	14.59 Max	-----	6.10 Min	100.00	547	.648	-----	-----
			7	4.37	.59	13.14	29.42	31.70	14.51	-----	6.26	99.99 Min	548 Max	.649	-----	-----
			8	4.40	.60	13.06	29.30	31.79	14.56	-----	6.23	99.99	547	.648	-----	-----
			9	4.43 Max	.53 Min	13.18 Max	29.33	31.70	14.53	-----	6.30	100.00	548	.649	-----	-----
			10	4.35 Min	.55	13.13	29.25 Min	31.99 Max	14.47	-----	6.25	99.99	547	.646 Min	-----	-----
			Avg.	4.39±0.02	0.61±0.04	13.08±0.05	29.39±0.03	31.77±0.03	14.50±0.04	-----	6.26±0.05	100.00	546.7±1	0.6485±0.0007	-----	-----

TABLE 3.—Analysis of Standard Gas Sample ASTM D-3-VII-1 (carburetted water-gas type)—Continued

Laboratory No.	Apparatus	Method	Analysis No.	CO <sub>2</sub>	O <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	N <sub>2</sub>	Total	Btu/ft <sup>3</sup>	Specific gravity	As reported by laboratories <sup>1</sup>	
															Btu	Sp gr
1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16
6	{V <sub>1</sub> R <sub>1</sub> Hg U. S. Steel. (0.02)-----}	I-2-1	1	4.50 Min	0.90	13.45 Max	29.65 Min	33.60	8.50	2.65 Max	6.75	-----	546 Max	0.660	-----	-----
			2	4.50	1.00 Max	13.40	29.75	33.45 Min	8.70 Max	2.35 Min	6.85 Max	-----	541 Min	.661 Max	-----	-----
			3	4.60 Max	0.85	13.10 Min	30.05 Max	33.95	8.30 Min	2.65	6.50	-----	541	.658	-----	-----
			4	4.55	.80 Min	13.25	29.95	33.95	8.50	2.65	6.35 Min	-----	545	.657	-----	-----
			5	4.55	.85	13.25	29.95	34.00 Max	8.40	2.65	6.35	-----	545	.656 Min	-----	-----
			Avg.	4.54±0.03	0.88±0.06	13.29±0.11	29.87±0.14	33.79±0.21	8.48±0.10	2.59±0.10	6.56±0.19	-----	543.6±2	0.658±0.002	-----	-----
7	{V <sub>2</sub> R <sub>2</sub> Hg Modified Hempel. (0.05)-----}	I-1-1	1	3.96 Min	0.99	12.72	30.17 Max	32.99 Min	10.00 Min	0.98 Min	8.19 Max	-----	519.6 Min	0.655 Max	-----	-----
			2	4.2	.84 Min	12.7 Min	29.84	33.55	10.59 Max	1.06 Max	7.22 Min	-----	527.2	.649	-----	-----
			3	4.3 Max	.94	12.9	29.65	34.03 Max	11.32*	0.54*	6.32*	-----	529.5 Max	.642 Min	-----	-----
			4	4.3	1.15 Max	12.98 Max	29.13 Min	33.43	10.44	0.99	7.58	-----	526.8	.652	-----	-----
			Avg.	4.19±0.12	0.98±0.09	12.83±0.10	29.70±0.41	33.50±0.29	10.59±0.37	0.89±0.18	7.33±0.56	-----	526±3	0.650±0.004	534.8	-----
			Avg.	4.19±0.12	0.98±0.09	12.83±0.10	29.70±0.41	33.50±0.29	10.59±0.37	0.89±0.18	7.33±0.56	-----	526±3	0.650±0.004	534.8	-----
8	{V <sub>1</sub> R <sub>1</sub> Hg Bureau of Mines-----}	I-1-1	1	4.4	0.7	13.2	30.1	34.7	8.1	3.0	5.8	-----	549.0	0.660	-----	-----
			2	4.4	.8 Max	13.2	29.9 Min	34.4	9.0 Max	2.6 Min	5.7	-----	549.4	.651 Min	-----	-----
			3	4.5 Max	.6 Min	13.1	30.1	34.5	8.4	2.9	5.9	-----	548.0	.661	-----	-----
			4	4.5	.6	13.0 Min	30.1	34.4	7.6	3.4	6.4	-----	546.9 Min	.665	-----	-----
			5	4.4	.7	13.1	30.0	34.4	8.4	3.0	6.0	-----	549.2	.653	-----	-----
			6	4.4	.7	13.3	30.2 Max	34.2 Min	7.4	3.4	6.4	-----	549.4	.660	-----	-----
			7	4.4	.6	13.2	30.1	34.2	6.9 Min	3.5 Max	7.1 Max	-----	544.2	.670 Max	-----	-----
			8	4.5	.6	13.3	30.1	34.6	7.0	3.5	6.4	-----	548.1	.666	-----	-----
			9	4.3 Min	.7	13.3	30.2	34.8 Max	7.6	3.5	5.6 Min	-----	555.2 Max	.653	-----	-----
			10	4.5	.6	13.4 Max	30.0	34.6	7.2	3.5	6.2	-----	551.4	.657	-----	-----
			Avg.	4.43±0.06	0.66±0.06	13.21±0.09	30.08±0.07	34.5±0.2	7.8±0.6	3.2±0.3	6.2±0.35	-----	549.0±2	0.656±0.006	558.6	-----
			Avg.	4.43±0.06	0.66±0.06	13.21±0.09	30.08±0.07	34.5±0.2	7.8±0.6	3.2±0.3	6.2±0.35	-----	549.0±2	0.656±0.006	558.6	-----
9	{V <sub>1</sub> R <sub>1</sub> Hg U. S. Steel. (0.23)-----}	II-1-1	1	3.6*	0.6*	13.6*	29.9*	34.8*	8.2*	2.7*	6.6*	-----	551*	0.646*	-----	-----
			2	4.3*	.7*	13.7*	28.9*	33.0*	11.1*	1.4*	6.9*	-----	550*	.653*	-----	-----
			3	4.3 Min	.8 Max	13.2	29.3 Min	34.8	8.6	2.4	6.6	-----	541	.651	-----	-----
			4	4.3	.8	13.2	29.4	34.7	8.1 Min	2.7 Max	6.8 Max	-----	542	.651	-----	-----
			5	4.4	.6 Min	13.2	29.4	34.8	8.9	2.1 Min	6.6	-----	539 Min	.647	-----	-----
			6	4.5 Max	.8	13.4	29.5 Max	34.9	9.0 Max	2.7	5.2 Min	-----	555 Max	.647	-----	-----
			7	4.5	.6	13.4	29.5	34.6 Min	8.8	2.1	6.5	-----	541	.649	-----	-----
			8	4.5	.6	13.5 Max	29.3	34.7	8.1	2.6	6.7	-----	544	.652 Max	-----	-----
			9	4.4	.6	13.3	29.4	34.6	8.8	2.4	6.5	-----	545	.649	-----	-----
			10	4.5	0.6	13.1 Min	29.5	35.1 Max	8.6	2.3	6.3	-----	540	.646 Min	-----	-----
			Avg.	4.42±0.07	0.68±0.08	13.28±0.11	29.41±0.06	34.8±0.1	8.6±0.3	2.4±0.2	6.4±0.3	-----	545±4	0.649±0.002	552.72	-----
			Avg.	4.42±0.07	0.68±0.08	13.28±0.11	29.41±0.06	34.8±0.1	8.6±0.3	2.4±0.2	6.4±0.3	-----	545±4	0.649±0.002	552.72	-----

10	$\left\{ \begin{array}{l} V_1R_1Hg \\ \text{Burrell} \\ (0.20) \end{array} \right\}$	II-1-1	1	4.45	0.51	12.76 Min	30.33	35.04	8.04	3.30	5.57 Min		548.5	0.6492	558.2	
			2	4.40	.50 Min	13.00	29.09	34.63	9.03 Max	3.26	6.09		556.3	.6484	556.1	
			3	3.61*	.60	13.53 Max	28.65 Min	34.69	8.40	3.40	7.12 Max		559.7 Max	.6464 Min	569.5	
			4	4.31 Min	.59	12.82	30.74 Max	34.75	7.53	2.87	6.34		537.8 Min	.6526	547.2	
			5	4.42	.59	13.26	29.87	34.58	7.71	3.04	6.43		545.6	.6534	555.3	
			6	4.33	.60	12.99	29.20	35.26	7.75	3.68 Max	6.19		553.1	.6481	557.9	
			7	4.31	.69 Max	12.93	29.97	34.57	8.03	2.74 Min	6.76		538.6	.6523	545.7	
			8	4.33	.69	13.18	30.19	33.93 Min	8.67	3.18	5.83		555.4	.6561 Max	565.2	
			9	4.52 Max	.69	12.87	29.18	35.47 Max	7.48 Min	3.27	6.52		541.8	.6483	548.5	
			10	4.41	.69	13.12	29.09	35.26	8.02	3.26	6.15		550.1	.6472	556.9	
Avg.			4.45±0.08	0.62±0.06	13.05±0.18	29.63±0.39	34.82±0.35	8.07±0.38	3.20±0.21	6.29±0.34		548.8±6	0.6502±0.003	556.1		
11	$\left\{ \begin{array}{l} V_1R_1Hg \\ \text{Shepherd} \\ (0.01) \end{array} \right\}$	III-1-1	1	4.37 Max	0.54	11.59 Min	30.48	30.42 Min	16.95	5.66	100.01	546.5	0.6507 Max			
			2	4.20 Min	.59 Max	11.83	30.53 Max	30.53	17.06 Max	5.33 Min	100.07 Max	551.9 Max	.6488 Min			
			3	4.33	.45 Min	12.15 Max	30.21 Min	30.91 Max	15.84 Min	6.10 Max	99.99 Min	545.0 Min	.6503			
			Avg.			4.30±0.07	0.53±0.05	11.86±0.20	30.41±0.13	30.62±0.19	16.62±0.51	5.70±0.27	100.02	547.8±3	0.6499±0.001	
12	$\left\{ \begin{array}{l} V_1R_1Hg \\ \text{Burrell} \\ (0.05) \end{array} \right\}$	I-1-1	1	4.33 Min	0.82	13.08	30.50	36.25 Max	7.48 Min	3.37	4.53 Min	100.36	541 Max	0.635	550	
			2	4.48	.81	13.13	30.10	35.10	7.56	3.71 Max	5.80	100.69	533	.649	542	
			3	4.48	.82 Max	13.27 Max	31.55 Max	33.20	9.08	2.04	6.23	100.87	534	.658	543	
			4	4.48	.82	13.16	31.00	33.07 Min	8.88	2.45	7.14	100.99	535	.665	544	
			5	4.44	.81	13.13	30.70	33.80	9.23	2.15	5.65	99.91	534	.645	543	
			6	4.44	.72 Min	13.13	31.00	33.55	9.88	1.78	5.54	100.02	534	.645	543	
			7	4.43	.80	13.07	30.04	33.60	9.86	1.81	7.35	100.96	530	.654	539	
			8	4.52 Max	.80	12.97 Min	30.65	33.58	9.95	1.71	6.91	101.09	530	.655	539	
			9	4.44	.81	13.02	30.08	33.72	10.75 Max	1.08 Min	8.68 Max	102.48 Max	526 Min	.667 Max	535	
			10	4.33	.81	13.00	29.71 Min	34.42	10.62	1.28	5.13	99.29 Min	530	.626 Min	539	
Avg.			4.44±0.04	0.80±0.02	13.10±0.07	30.53±0.45	34.03±0.75	9.33±0.88	2.14±0.63	6.30±0.97	100.66	533±3	0.650±0.010	542		
13	$\left\{ \begin{array}{l} V_1R_1Hg \\ \text{Burrell} \\ \text{(built-up)} \\ (0.0) \end{array} \right\}$	II-1-1	1	4.3	0.7	13.2	28.9	34.9	7.8 Min	1.8 Min	8.4 Max		535	0.647	530.966	(Density 0.8397858
			2	4.3	.7	12.7 Min	29.3 Max	35.1	8.1	2.7 Max	7.1		522 Min	.650 Max	543.983	.8366846
			3	4.4 Max	.9 Max	13.3 Max	28.9	34.9	8.9 Max	2.3	6.4		543	.646	552.696	.8354037
			4	4.3	.8	13.1	28.8	35.2 Max	8.8	2.4	6.6		541	.643 Min	550.895	.8316517
			5	4.4	.8	13.2	29.2	34.8	8.6	2.7	6.3 Min		546 Max	.648	555.836	.8283964
			6	4.4	.8	13.1	29.0	34.9	8.6	2.6	6.6		543	.647	552.113	.8371401
			7	4.4	.9	13.3	28.7 Min	35.2	8.2	2.7	6.6		544	.647	553.083	.8361014
			8	4.2 Min	.6 Min	13.2	29.3	34.7 Min	8.9	2.1	7.0		539	.646	548.138	.8355508
			9	4.3	.8	13.2	29.0	35.0	8.8	2.5	6.4		545	.645	554.293	.8340749
			10	4.4	.8	13.2	29.1	34.9	8.7	2.5	6.4		546	.647	553.274	.8364959
Avg.			4.34±0.06	0.78±0.07	13.14±0.11	29.02±0.16	34.96±0.13	8.54±0.30	2.43±0.22	6.78±0.43		540±5	0.647±0.001	559		



TABLE 3.—Analysis of Standard Gas Sample ASTM D-3-VII-1 (carburetted water-gas type)—Continued

Laboratory No.	Apparatus	Method	Analysis No.	CO <sub>2</sub>	O <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	N <sub>2</sub>	Total	Btu/ft <sup>3</sup>	Specific gravity	As reported by laboratories <sup>1</sup>	
															Btu	Sp gr
1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16
14	{V <sub>1</sub> R <sub>1</sub> Hg— Shepherd- Burrell}	II-1-1	1	4.40 % Min	0.60 % Min	12.81 %	29.58 %	35.44 % Max	8.45 %	3.03 %	5.82 %	100.16 %	548	0.644	-----	-----
			2	4.45	.60	12.91 Max	29.33	35.29	8.45	3.03	5.90 Max	99.96	548	.644	-----	-----
			3	4.50	.70	12.91	29.53	35.09 Min	8.51	3.00	5.84	100.08	548	.647	-----	-----
			4	4.56	.80 Max	12.79	29.48	35.20	8.48	2.98	5.88	100.17	546	.648 Max	-----	-----
			5	4.52	.70	12.76 Min	29.25 Min	35.22	8.45	3.01	5.87	99.78 Min	545 Min	.644	-----	-----
			6	4.43	.70	12.78	29.51	35.44	8.55	2.91	5.80	100.12	546	.645	-----	-----
			7	4.50	.65	12.85	29.65	35.25	8.39 Min	3.11 Max	5.77	100.17	549 Max	.643 Min	-----	-----
			8	4.50	.70	12.81	29.43	35.24	8.64	2.83 Min	5.76	99.91	545	.644	-----	-----
			9	4.55 Max	.60	12.80	29.90 Max	35.10	8.66	2.87	5.71	100.19 Max	547	.646	-----	-----
			10	4.40	.60	12.86	29.78	35.34	8.69 Max	2.84	5.64 Min	100.15	548	.643	-----	-----
			Avg.	4.49±0.04	0.67±0.05	12.83±0.04	29.52±0.12	35.25±0.08	8.51±0.07	2.97±0.07	5.82±0.05	100.07	547.0±1.1	0.6448±0.0012	-----	-----
			1	4.6 Max	0.6 Min	13.0	30.1	34.5	-----	-----	-----	-----	-----	-----	-----	-----
			2	4.5	.7	13.0	30.1	34.0	-----	-----	-----	-----	-----	-----	-----	-----
			3	4.5	.8	12.8 Min	29.9 Min	34.6	9.4	2.6	5.4	-----	547.6	0.648	-----	-----
15	{V <sub>1</sub> R <sub>1</sub> Hg— U. S. Steel- Shepherd (0.0)}	I-1-1	4	4.4 Min	.7	13.1 Max	30.2	34.5	6.8 Min	3.7 Max	6.6 Max	-----	546.5 Min	.659 Max	-----	-----
			5	4.4	.9 Max	12.9	30.3 Max	34.8 Max	11.3 Max	1.9 Min	3.5 Min	-----	557.8 Max	.637 Min	-----	-----
			6	4.5	.6	13.1	30.0	33.7 Min	10.4	2.2	5.6	-----	552.7	.652	-----	-----
			Avg.	4.48±0.06	0.71±0.08	12.98±0.09	30.10±0.10	34.35±0.30	9.5±1.4	2.6±0.5	5.3±0.9	-----	551.3±4	0.649±0.006	-----	-----
			7	4.6	0.8	13.0	30.6	36.5	9.2	3.0	2.3	-----	-----	-----	-----	-----
			II-1-1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
		II-1-1	1	4.55 Max	0.70 Max	12.40	29.65	35.60	-----	-----	-----	-----	-----	-----	-----	-----
			2	4.50	.70	12.20	30.40	35.05	-----	-----	-----	-----	-----	-----	-----	-----
			3	4.50	.70	12.05 Min	30.50 Max	34.90 Min	-----	-----	-----	-----	-----	-----	-----	-----
			4	4.50	.70	12.05	29.95	35.90 Max	7.00 Min	3.70 Max	6.20	-----	535.5 Min	0.6465	-----	-----
			5	4.50	.60 Min	12.15	30.35	35.20	7.40	3.45	6.35 Max	-----	535.6	.6507 Max	-----	-----
			6	4.50	.60	12.25	30.25	35.25	7.75	3.45	5.95	-----	540.6	.6489	-----	-----
			7	4.50	.65	12.30	30.40	35.65	7.60	3.55	5.35 Min	-----	543.4	.6460	-----	-----
			8	4.50	.60	12.70 Max	30.05	35.75	8.10	2.70	5.60	-----	544.0 Max	.6423 Min	-----	-----
16	{V <sub>1</sub> R <sub>1</sub> Hg— Burrell- Oberfell (0.05)}	II-1-1	9	4.40 Min	.60	12.70	29.70	35.35	7.70	3.35	6.20	-----	544.0	.6477	-----	-----
			10	4.50	.60	12.45	29.50 Min	35.45	8.65 Max	2.65 Min	6.20	-----	536.9	.6423	-----	-----
			Avg.	4.50±0.01	0.65±0.05	12.30±0.19	30.05±0.30	35.40±0.27	7.75±0.27	3.25±0.33	6.00±0.29	-----	537.8±2	0.6465±0.002	538.7	-----

17	$\left\{ \begin{array}{l} \text{V}_1\text{R}_1\text{Hg} \\ \text{Burrell-} \\ \text{Build-up} \\ (0.03) \end{array} \right\}$	I-2-1	1	4.45	0.70 Min	13.85 Max	29.25	33.05	9.90	1.85	6.95	-----	549.1 Max	0.658 Min	851.1	-----
			2	4.65 Max	.80	13.65	29.10 Min	32.80	9.94	1.73 Min	7.33	-----	542.9	.662	855.4	-----
			3	4.55	.80	13.55	29.35	33.05	9.61	1.97	7.12	-----	544.0	.660	853.6	-----
			4	4.60	.80	13.35 Min	29.35	33.10	9.91	1.97	6.72	-----	543.9	.659	851.9	-----
			5	4.60	.80	13.50	29.50	33.30 Max	9.40	2.20	6.70 Min	-----	546.3	.659	852.4	-----
			6	4.60	.80	13.48	29.48	33.10	9.35 Min	2.34 Max	6.92	-----	547.3	.661	854.7	-----
			7	4.53	.75	13.60	29.25	33.00	10.01 Max	1.77	7.02	-----	544.6	.659	852.2	-----
			8	4.60	.85	13.40	29.55 Max	32.30	9.66	2.07	7.67 Max	-----	542.0 Min	.667 Max	862.0	-----
			9	4.50	.90 Max	13.65	29.35	32.95	9.44	2.23	6.98	-----	548.0	.662	856.0	-----
			10	4.43 Min	.82	13.40	29.49	32.28 Min	9.96	2.02	7.60	-----	543.0	.665	859.9	-----
			Avg.	4.54±0.06	0.80±0.03	13.56±0.10	29.36±0.11	32.91±0.26	9.72±0.23	2.02±0.16	7.11±0.27	-----	545.2±2	0.661±0.002	854.9	-----
			1	4.61 Max	1.15 Max	12.67 Min	28.59	35.29 Min	9.10	3.30 Max	5.29	-----	553	0.650 Max	553.0	-----
			2	4.51	.62	13.03	28.31 Min	37.03	6.64 Min	2.28 Min	7.58 Max	-----	520.9 Min	.638	520.9	-----
			3	4.38 Min	.71	12.95	29.15 Max	36.70	7.59	3.19	5.33	-----	546.5	.637	546.5	-----
			4	4.44	.61	13.13	28.89	37.78 Max	8.28	2.78	4.09 Min	-----	551.9	.624 Min	551.9	-----
			5	4.47	.53 Min	13.21 Max	28.65	35.36	11.07 Max.	2.34	4.37	-----	564.7 Max	.634	564.7	-----
			Avg.	4.48±0.06	0.72±0.15	13.00±0.15	28.72±0.24	36.43±0.62	8.54±1.26	2.78±0.37	5.33±0.90	-----	548±11	0.637±0.006	-----	-----
			1'	4.33 Min	0.52 Max	12.37	29.48	35.26 Min	9.08	2.98	5.98 Max	-----	545.1	0.643 Max	-----	-----
			2'	4.36	.52	12.34 Min	29.67 Max	35.37	9.14	2.99 Max	5.61	-----	546.4 Min	.642	-----	-----
			3'	4.46 Max	.32 Min	12.65	29.44	36.03 Max	8.98 Min	2.99	5.13 Min	-----	551.2 Max	.637 Min	-----	-----
			4'	4.44	.52	12.81 Max	29.34 Min	35.54	9.23 Max	2.82 Min	5.30	-----	551.2	.641	-----	-----
			5'	4.36	.52	12.67	29.60	35.62	8.99	2.96	5.28	-----	550.3	.641	-----	-----
			Avg.	4.39±0.05	0.48±0.08	12.57±0.21	29.51±0.10	35.56±0.21	9.08±0.08	2.95±0.05	5.46±0.27	-----	549±2	0.641±0.001	-----	-----
18	$\left\{ \begin{array}{l} \text{V}_1\text{R}_1\text{Hg} \\ \text{S. Cal. Co.-} \\ \text{Burton} \\ (0.0) \end{array} \right\}$	II-2-1 Analyst 2	1''	4.4 Min	0.6	13.1	28.8 Min	35.2	8.7	2.9 Min	6.3	-----	549	0.646	-----	-----
			2''	4.5 Max	.5 Min	13.3 Max	29.2	35.6 Max	8.5	2.9	5.5 Min	-----	553	.644 Min	-----	-----
			3''	4.4	.7 Max	13.2	30.9 Max	33.3 Min	2.1*	7.0*	8.4 Max	-----	558 Max	.696 Max	-----	-----
			4''	4.5	.6	13.0 Min	28.8	35.0	8.9 Max	3.1	6.1	-----	552	.648	-----	-----
			5''	4.4	.6	13.1	29.1	35.2	7.9 Min	3.2 Max	6.5	-----	547.4 Min	.650	-----	-----
			Avg.	4.45±0.05	0.58±0.04	13.13±0.09	28.98±0.18	35.25±0.18	8.50±0.30	3.03±0.13	6.10±0.30	-----	550±2	0.647±0.002	-----	-----
		II-2-1 Analyst 3	1''	4.4 Min	0.6	13.1	28.8 Min	35.2	8.7	2.9 Min	6.3	-----	549	0.646	-----	-----
			2''	4.5 Max	.5 Min	13.3 Max	29.2	35.6 Max	8.5	2.9	5.5 Min	-----	553	.644 Min	-----	-----
			3''	4.4	.7 Max	13.2	30.9 Max	33.3 Min	2.1*	7.0*	8.4 Max	-----	558 Max	.696 Max	-----	-----
			4''	4.5	.6	13.0 Min	28.8	35.0	8.9 Max	3.1	6.1	-----	552	.648	-----	-----
			5''	4.4	.6	13.1	29.1	35.2	7.9 Min	3.2 Max	6.5	-----	547.4 Min	.650	-----	-----
			Avg.	4.45±0.05	0.58±0.04	13.13±0.09	28.98±0.18	35.25±0.18	8.50±0.30	3.03±0.13	6.10±0.30	-----	550±2	0.647±0.002	-----	-----

TABLE 3.—Analysis of Standard Gas Sample ASTM D-3-VII-1 (carburetted water-gas type)—Continued

Laboratory No.	Apparatus	Method	Analysis No.	CO <sub>2</sub>	O <sub>2</sub>	C <sub>2</sub> H <sub>4</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	N <sub>2</sub>	Total	Btu/ft <sup>3</sup>	Specific gravity	As reported by laboratories <sup>1</sup>		
															Btu	Sp gr	
1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
19	{Gockel----- (0.1)}	I-1-2	1	%	%	%	%	%	%	%	%	%	%				
			2	4.45	0.80	12.26	31.07	34.32	8.03 Max	2.40 Min	6.67	-----	524.7	0.6552	-----	-----	
			3	4.50 Max	.80	12.40	30.80	34.40	7.51	2.92	6.67	-----	530.4	.6573	-----	-----	
			4	4.48	.89	12.25	30.97	34.51	7.60	2.54	6.76	-----	523.0 Min	.6557	-----	-----	
			5	4.50	.70 Min	12.30	31.10 Max	34.50	7.42	2.89	6.59	-----	528.5	.6567	-----	-----	
			6	4.40 Min	.70	12.50 Max	30.90	34.80 Max	7.34	2.85	6.51	-----	530.6	.6539 Min	-----	-----	
			7	4.40	.90 Max	12.32	30.75	34.73	7.10 Min	3.04	6.76	-----	527.9	.6558	-----	-----	
			8	4.49	.80	12.39	30.89	34.43	7.67	2.69	6.64	-----	527.8	.6554	-----	-----	
			9	4.50	.90	12.11 Min	30.91	34.58	7.42	3.18	6.40 Min	-----	530.2	.6564	-----	-----	
			10	4.44	.70	12.39	30.84	34.23 Min	7.13	3.20 Max	7.07 Max	-----	530.8 Max	.6603 Max	-----	-----	
			11	4.42	.90	12.35	30.72 Min	34.64	7.44	2.75	6.78	-----	526.3	.6551	-----	-----	
			Avg.	4.46±0.03	0.80±0.07	12.33±0.08	30.91±0.11	34.50±0.13	7.47±0.19	2.84±0.20	6.69±0.13	-----	528.0±2	0.6562±.001	528.3	0.6564	
By Distillation (small sample)				1	4.46	0.80	12.37	30.45	34.31	7.40	3.52	6.69	-----	538	0.664	-----	
20	{V <sub>4</sub> R <sub>2</sub> Hg----- Bone-Wheeler.	I-2-2	1	4.30	0.61	12.64	30.38	33.32	8.87	2.80	7.08	-----	540.8	0.6600	-----	-----	
			2	4.32	.88	12.41	30.10	33.36	9.06	2.80	7.07	-----	538.3	.6593	-----	-----	
			Avg.	4.31±0.005	0.75±0.07	12.52±0.05	30.24±0.07	33.34±0.01	8.97±0.05	2.80	7.07±0.005	-----	539.6±0.6	0.6597±0.0003	-----	-----	
21	{V <sub>1</sub> R <sub>1</sub> Hg----- Bureau of Mines (0.01)-----}	II-1-1	1	4.4 Min	0.9	13.6 Max	28.8	34.2	8.3	2.8	7.0	-----	548.1	0.656 Max	-----	-----	
			2	4.4	.9	13.6	28.6	34.3	8.4	2.8	7.0	-----	548.9 Max	.654	-----	-----	
			3	4.4	.6 Min	13.1	29.2	34.6	8.5	2.9	6.7 Min	-----	546.5	.651	-----	-----	
			4	4.4	.7	13.0 Min	29.2	34.5	8.5	2.8	6.9	-----	542.9	.652	-----	-----	
			5	4.4	.7	13.1	29.3 Max	34.4	8.5	2.8	6.95	-----	542.1	.653	-----	-----	
			6	4.5 Max	.7	13.0	29.3	34.5	8.2 Min	3.0 Max	6.8	-----	543.7	.654	-----	-----	
			7	4.4	1.2 Max	13.3	28.4 Min	34.0 Min	8.6 Max	2.4 Min	7.9 Max	-----	534.3 Min	.647 Min	-----	-----	
			8	4.4	0.9	13.1	29.0	34.6	8.5	2.7	6.9	-----	540.8	.652	-----	-----	
			9	4.4	1.0	13.1	28.9	34.7 Max	8.2	2.9	7.0	-----	538.9	.651	-----	-----	
			Avg.	4.41±0.02	0.84±0.15	13.13±0.21	28.97±0.26	34.42±0.18	8.41±0.12	2.79±0.11	7.02±0.20	-----	543±4	0.652±0.002	544	0.654	

22	{V <sub>1</sub> R <sub>1</sub> Hg----- (0.07)}	I-1-2	1	4.4	0.10 Min	12.5 Max	30.2	34.1 Min	8.0	3.5	6.3	544 Max	0.658 Max			
			2	4.4	.12	12.5	30.1	34.3	7.9	3.3	6.3	540	.657			
			3	4.4	.13	12.3 Min	30.3 Max	34.1	8.6 Max	2.9	6.1	537	.655			
			4	4.4	.14	12.3	30.2	34.6	8.1	2.9	6.1	533 Min	.654			
			5	4.2 Min	.14	12.5	30.0 Min	34.5	8.5	2.9	6.0	539	.651 Min			
			6	4.3	.12	12.4	30.2	34.4	8.3	2.8 Min	6.4 Max	534	.654			
			7	4.4	.13	12.3	30.1	34.8 Max	7.9	3.2	6.0	537	.653			
			8	4.4	.15 Max	12.3	30.0	34.6	8.5	2.9	5.8 Min	537	.652			
			9	4.4	.13	12.3	30.0	34.8	7.6 Min	3.6 Max	6.0	540	.654			
			10	4.5 Max	.13	12.4	30.0	34.6	7.7	3.5	6.0	541	.656			
			Avg.	4.38±0.05	.129±0.09	12.38±0.08	30.11±0.09	34.48±0.21	8.11±0.29	3.15±0.27	6.10±0.14	538±3	0.654±0.002			
23	{V <sub>2</sub> R <sub>1</sub> Hg----- Fischer Uni- tized (0.3)}	I-1-1	1	4.80	1.77 Max	14.93	29.04	31.38	8.33 Min	2.15 Max	7.60	550	0.684			
			2	4.70 Min	1.36 Min	14.90	28.92	32.13	9.70	1.89	6.40	560 Max	.670			
			3	4.71	1.47	15.21 Max	28.54	31.21	9.66	1.21	7.99	549	.678			
			4	4.76	1.38	14.81	28.56	34.29 Max	9.36	1.48 Min	5.36 Min	555	.652 Min			
			5	4.77	1.51	14.91	29.47	30.33 Min	8.36	1.93	8.72 Max	544	.693 Max			
			6	4.91 Max	1.37	14.76	28.98	31.35	9.75	1.90	7.98	547	.682			
			7	4.78	1.44	14.81	29.61 Max	30.91	9.02	1.54	7.89	555	.684			
			8	4.78	1.43	14.81	29.14	31.34	9.97 Max	1.62	6.91	555	.677			
			9	4.71	1.41	14.26 Min	28.71	31.99	9.28	1.52	8.12	538 Min	.673			
			10	4.81	1.50	15.04	28.25 Min	30.99	9.34	1.65	8.50	549	.677			
			Avg.	4.77±0.04	1.46±0.08	14.84±0.15	28.92±0.32	31.58±0.73	9.18±0.45	1.69±0.22	7.55±0.79	549±5	0.677±0.007			
24	{V <sub>1</sub> R <sub>1</sub> Hg----- Shepherd (0.02)}	III-1-1.	1	4.45	0.53	12.96	29.96	31.98	14.35	-----	5.77	100.00 Max	545.6	0.6478		
			2	4.49 Max	.56	12.90 Min	29.99	31.91	14.36	-----	5.79	100.00	544.6 Min	.6483		
			3	4.46	.61 Max	12.93	29.95	31.91	14.37	-----	5.76	99.99 Min	545.1	.6485 Max		
			4	4.42	.49 Min	12.97	29.91 Min	31.99	14.39	-----	5.82 Max	99.99	546.0	.6467 Min		
			5	4.43	.53	13.00 Max	29.95	32.03	14.34 Min	-----	5.72	100.00	546.3	.6473		
			6	4.42	.55	12.99	30.01	31.94	14.37	-----	5.73	100.00	546.4	.6478		
			7	4.40	.60	12.96	29.91	31.84 Min	14.50 Max	-----	5.78	99.99	546.5	.6483		
			8	4.39 Min	.55	12.98	29.92	31.95	14.40	-----	5.80	99.99	546.2	.6472		
			9	4.45	.57	12.99	29.93	31.96	14.48	-----	5.62	100.00	547.3 Max	.6471		
			10	4.48	.55	12.94	30.02 Max	32.03 Max	14.37	-----	5.61 Min	100.00	545.9	.6472		
			Avg.	4.44±0.03	0.55±0.03	12.96±0.02	29.96±0.03	31.95±0.04	14.39±0.04	-----	5.74±0.06	-----	546.0±0.6	0.6476±0.001		
			1	-----	0.57 Max	-----	-----	-----	-----	-----	-----	-----	-----			
			2	4.35 Min	.47	12.83	29.61	31.98	14.71	-----	5.97 Max	-----	545.1 Min	0.6460		
			3	4.41	.49	12.77	29.82	31.89 Min	14.80 Max	-----	5.76	-----	546.4 Max	.6465 Max		
			4	4.45	.53	12.71 Min	29.72	32.06	14.72	-----	5.77	-----	545.8	.6452		
			5	4.51 Max	.52	12.74	29.50 Min	32.23	14.75	-----	5.79	-----	545.9	.6436 Min		
			6	4.47	.46 Min	12.86 Max	30.03 Max	32.29 Max	14.51 Min	-----	5.44 Min	-----	545.4	.6441		
			7	-----	.54	12.78	-----	-----	-----	-----	-----	-----	-----	-----		
Avg.	4.44±0.05	0.51±0.03	12.78±0.04	29.74±0.15	32.09±0.14	14.70±0.07	-----	5.74±0.12	-----	545.7±0.4	0.6450±0.001					

<sup>1</sup> Only those data which differ from columns 13 and 14 are given.

WASHINGTON, May 24, 1945.